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EXPERIMENTATION WITH VARIOUS METHODS OF DE-ICING AND ANTI-ICING FOR SHIPS

TP 9948E

for

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Un sommaire en francais de ce rapport est inclus avant la table des matieres.

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17. Abstract

The purpose of this study was to improve ship and personnel safety and the practical operability of vessels exposed to severe ice accretion by experimentation with some icing control systems. As an initial test of selected ice phobic coatings, a series of laboratory experiments was completed. Shipboard tests conducted during the winters of 1988 and 1989 assessed the efficiency of all of the de-icing/anti-icing methods under consideration (ice phobic paints, heating panels, air hammer, and inflatable panels).

The conclusions are that; (a) silicone-based coatings exhibited good ice phobic properties in combination with acceptable ice adhesion, abrasion and impact properties, except for Defro S-III (which had a low abrasion resistance), (b) heated panels are a practical means of anti-icing and de-icing but, (c) inflatable panels seem to be the most effective for de-icing, and will be the least energy consuming. The overall recommendation is that research should continue. This project was adversely affected by mild weather and only further testing will allow firm recommendations to be made.

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16. Résumé

Ce rapport concerne l'expérimentation de certains moyens de lutte contre le givrage dans le but d'étendre les limites d'exploitabilité des navires soumis à des conditions extrêmes de givrage tout en renforçant la sécurité aussi bien des équipages que des navires eux-mêmes. Des études antérieures avaient montré que les moyens thermiques et mécaniques étaient les plus efficaces lorsqu'ils sont combinés à l'utilisation de revêtements spéciaux antigivrage.

Une série d'expérience en laboratoire a été menées afin de mettre à l'épreuve certains revêtements antigivrage choisis. Puis, des essais en mer on eu lieu durant l'hiver 1988 et celui de 1989 pour vérifier l'efficacité de l'ensemble des moyens de lutte contre le givrage envisagés (revêtements antigivrage, panneaux chauffants, pistolets à air et panneaux gonflables).

Les conclusions de l'étude sont : a) les trois revêtements à base de silicone ont affiché de bonnes propriétés antigivrage, caractérisées par un coefficient d'accrochage et une résistance à l'abrasion et aux chocs acceptables, sauf le Defro S-III (dont la résistance à l'abrasion est faible); b) les panneaux chauffants constituent un moyen pratique d'antigivrage et de dégivrage; c) les panneaux gonflables semblent les plus efficaces côté dégivrage, il est certain que ceux-ci sont les moins énergivores. La principale recommandation vise la poursuite de la recherche. Le climat doux a contrecarré les projets des chercheurs, et seulement la reprise des essais permettra de déboucher sur des recommandations fermes.

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EXECUTIVE SUMMARY

The purpose of this study was to improve ship and personnel safety and the practical operability of vessels exposed to severe ice accretion by experimentation with some icing control systems. Although it was suggested that only small vessels were exposed to the danger of capsizing due to icing, the evidence implies that the operation of all ships may be seriously impaired by icing due to: (a) hazardous working conditions on deck, (b) the immobilization of safety and deck equipment and, (c) freezing up of scuppers, etc.

From previous studies it was found that the most effective means of anti-icing and de-icing are thermal and mechanical methods combined with special surface coatings (ice phobic paints). Therefore, the final selection of methods for testing was limited to:

- Ice Phobic Paints,
- Electrical Trace Heating,
- Inflatable Panels, and
- Air Hammer

As an initial test of the selected ice phobic coatings, a series of laboratory experiments were completed. These were; (a) an Ice Adhesion Strength Test, (b) an Abrasion Resistance Test and, (c) an Impact Test.

The shipboard tests were designed to assess the efficiency of all of the de-icing/anti-icing methods under consideration. The 'CAPE ROGER' was used for testing ice phobic paint, heating panels, air hammer, and inflatable panels. The 'ASL SANDERLING' was used for ice phobic paint experiments. These ships were made available by the Department of Fisheries and Oceans and Atlantic Searoute Limited respectively. These experiments were conducted during February through March of 1988 and January through March of 1989; measurements and photographs of icing severity were taken where possible.

In general, the 1988 and 1989 icing seasons were very mild. Only thirteen icing events were recorded and, of these, only a few were of any consequence. Nevertheless, there was sufficient icing to make a minimal evaluation of all experiments except the Air Hammer - there was simply insufficient ice for removal by that means.

Due to a lack of severe icing events the overall objective was not achieved. However, much was learned. The conclusions which can be drawn are:

a) Ice Phobic Paints/Coatings

It appeared that the three silicone-based coatings exhibited good ice phobic properties in combination with acceptable ice adhesion, abrasion and impact properties, except for Defro S-III (which had a low abrasion resistance).

b) Heating Panels

Heated panels are a practical means of anti-icing and de-icing, particularly for the protection of sensitive equipment or machinery which is not sufficiently robust to withstand the use of heavy mallets.

c) Air Hammer

No conclusions can be drawn from these experiments since there was insufficient icing to allow the air hammer to be used.

d) Inflatable Panels

Of all the methods tested, these inflatable panels seemed to be most effective for de-icing, and will be the least energy consuming. These panels will remove ice from a protected surface and they can be used selectively, for equipment or sensitive area, or for large areas.

The overall recommendation which flows from this work is that research should continue on the general topic of the icing of ships. The two years' of experience obtained by this project was adversely affected by mild weather and, as a result, was inconclusive. Only further testing of specific solutions will increase the data base to the extent necessary to allow firm recommendations to be made.

SOMMAIRE

Ce rapport concerne l'expérimentation de certains moyens de lutte contre le givrage dans le but d'étendre les limites d'exploitabilité des navires, soumis à des conditions extrêmes de givrage, tout en renforçant la sécurité aussi bien des équipages que des navires eux-mêmes. Même si on laisse entendre que seuls les petits bateaux risquent de chavirer en raison de l'accumulation de givre, les données recueillies tendent à démontrer que le givrage peut sérieusement nuire à l'exploitation de tous les navires en raison : a) des conditions de travail dangereuses sur le pont, b) de l'immobilisation des apparaux de pont et de l'équipement de sauvetage et c) de l'accumulation de glace dans les dalots de pont, etc.

Des études antérieures avaient montré que les moyens thermiques et mécaniques étaient les plus efficaces lorsqu'ils sont combinés à l'utilisation de revêtements spéciaux antigivrage. Par conséquent, les méthodes finalement choisies pour les essais se sont limitées aux suivantes :

- Revêtements antigivrage,
- Rubans chauffants électriques,
- Panneaux gonflables, et
- Pistolet à l'air

D'abord, une série d'expériences en laboratoire ont été menées pour mettre à l'épreuve certains revêtements antigivrage choisis, et en déterminer a) le coefficient d'accrochage, b) la résistance à l'abrasion et c) la résistance aux chocs.

Les essais en mer avaient pour but de vérifier l'efficacité de l'ensemble des moyens de lutte contre le givrage envisagés. Le CAPE ROGER a servi pour mettre à l'épreuve un revêtement antigivrage, les panneaux chauffants, le pistolet à air et les panneaux gonflables. Le ASL SANDERLING a été utilisé pour les expériences sur les revêtements antigivrage. Ces navires ont été mis à notre disposition respectivement par Pêches et Océans Canada et la société Atlantic Searoute Limited. Ces expériences ont été menées entre février et mars 1988 et janvier et mars 1989; lorsque ce fut possible, on a mesuré les accumulations de glace et on a pris des photographies illustrant l'importance du givrage.

En général, les hivers 1988 et 1989 ont été marqués par un temps doux. Seulement treize jours de givrage ont été rapportés, et de ce nombre, seuls quelques-uns ont donné lieu à des accumulations non négligeables. Le givrage a tout de même été assez important pour permettre d'effectuer une évaluation minimale de toutes les méthodes à l'exception du pistolet à air puisque le givrage a été tout simplement insuffisant pour permettre son utilisation.

A cause de l'absence de conditions extrêmes de givrage, l'objectif global n'a pu être atteint mais un grand nombre de données ont pu être recueillies. On peut ainsi tirer les conclusions suivantes :

a) Revêtements antigivrage

Les trois revêtements à base de silicone ont affiché de bonnes propriétés antigivrage, caractérisées par un coefficient d'accrochage et une résistance à l'abrasion et aux chocs acceptables, sauf le Defro S-III (dont la résistance à l'abrasion est faible).

b) Panneaux chauffants

Les panneaux chauffants constituent un moyen pratique d'antigivrage et de dégivrage, surtout pour la protection du matériel et de la machinerie qui ne sont pas assez résistants pour être dégivrés à l'aide de lourds maillets.

c) Pistolet à air

Rien ne peut être dit à propos de ce moyen puisque le givrage n'a jamais été suffisant pour autoriser sa mise en oeuvre.

d) Panneaux gonflables

De toutes les méthodes expérimentées, les panneaux gonflables semblent les plus efficaces du côté dégivrage, tout en étant les moins énergivores. Ces panneaux brisent la glace accumulée sur les surfaces à protéger et peuvent être utilisés sélectivement, pour le matériel ou les surfaces fragiles, ou encore de grandes surfaces.

La principale recommandation de cette étude vise la poursuite de la recherche en ce qui a trait à l'accumulation de givre sur les navires. Le climat doux qui a prévalu au cours des deux derniers hivers a contrecarré les projets des chercheurs et les a empêchés d'obtenir des résultats concluants. Seule la reprise des essais permettra d'augmenter la base des données acquises sur certaines méthodes de dégivrage et de déboucher sur des recommandations fermes.

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1. INTRODUCTION

The purpose of this study was to improve ship and personnel safety and the practical operability of vessels exposed to severe ice accretion by experimentation with some icing control systems. The project is a continuation of a study completed in 1986 by Melville Shipping Ltd. on ship superstructure icing and its implications on ship safety (Evaluation and Definition of the Extent of Superstructure Icing as it may Relate to Ship's Safety and Operations for the East Coast of Canada). That study:

- explained the phenomenon of icing,
- reviewed the exposure to icing of various types of ships, and
- considered a number of possible anti-icing and de-icing measures

Although it was suggested that only small vessels were exposed to the danger of capsizing due to icing, the evidence implies that the operation of all ships may be seriously impaired by icing due to:

- hazardous working conditions on deck,
- the immobilization of safety and deck equipment,
- freezing up of scuppers, etc.

However, little work had been carried out onboard ships to investigate what could be done to reduce the hazards. To fill that gap, the present project intended to experiment on ship with some readily available methods of controlling icing on both a small and a large vessel.

During the previous study an extensive literature search was completed on icing control measures. As a result, it was possible to judge what measures could be most practically implemented on ships which are frequently and most seriously affected by icing. Therefore, any de-icing or anti-icing measures should be simple and of low cost.

The available anti-icing and de-icing methods can be grouped into three basic categories:

- methods incorporated in the ship design, such as good bow flare, minimization of rigging, aero dynamic shape of superstructure etc.,

- ship operation methods, which depend on a proper ship handling strategy, and

- methods based on special equipment, including surface coatings.

The first two groups are outside the scope of this project. The last group offers a range of technical means which can be employed on any ship regardless of its type and age. These include:

- surface coatings,
- chemical methods,
- thermal methods, and
- mechanical methods.

From the previous studies, listed at the back of this report, it was found that the most effective are thermal and mechanical methods combined with special surface coatings (ice phobic paints). Therefore, the final selection of methods for testing was limited to:

- ice phobic paints,
- electrical trace heating,
- inflatable panels, and
- air guns.

The ships chosen were the 'CAPE ROGER', a fisheries patrol vessel operated by the Department of Fisheries and Oceans, and the 'SANDERLING', a RORO vessel operated by Atlantic Searoute Ltd. Both ships operated off the east coast of Canada, in areas with a high frequency of icing.

In addition to shipboard tests the ice phobic paints were also evaluated by laboratory testing.

This report presents the background information, describes the tests and presents the test results, along with a discussion of the usefulness of these de-icing and anti-icing methods.

2. RESEARCH

2.1 Ice Phobic Paints

2.1.1 General

Since the objectives of this project were to evaluate practical coatings for marine applications, the scarcity of commercially available ice-phobic paints proved to be a difficulty. In addition to continuation of the literature search, ice phobic paint manufacturers and suppliers in Canada, the United States, Europe and Japan were contacted to obtain information. Eight different paints/coatings were identified as suitable for testing. Three of these paints are presently marketed as commercial products:

- Defro S-III, Kansai Paint Co. Ltd., Japan,
- Vellox 140, M-Chem Corp., USA, and
- Inerta 160, International Paints.

The others are still under development and only test samples were available. These paints are:

- S-2103 and S-2104, both from Hempel, Denmark,
- Baysilone VP AC3323, Bayer AG, West Germany,
- Thane 547, Futura Coatings, USA, and
- Intersilck, International Paint, Canada.

Manufacturers of these paints/coatings were requested to supply samples, instructions for application and specifications. The paints/coatings are described as follows:

a) Defro S-III (Kansai)

This is a composite material of an organopolysiloxane as a basic polymer and a unique organic-inorganic complex. The ice adhesion strength on this paint is claimed to be in the range of 5 to 15 kPa when measured at -10°C, probably with bulk frozen fresh water ice. The package consists of the silicone type undercoat and the two component main coatings, the colour of which is semi-transparent.

b) Vellox 140 (M-Chem Corp.)

This is a coating system consisting of two components: the primer, which is essentially a clear lacquer type coating; and a top coating, which is a suspension of a fine water repellent powder in a solution containing solvent and polymers. A Vellox 140 surface has a smooth finish. The nature of this surface limits the amount of abrasion that the surface can withstand. Vellox 140 is clear but pigmentation of both primers and top coats is possible.

c) Inerta 160 (International Paint)

This is a well known epoxy coating. Due to its smooth surface and resistance to abrasion, Inerta 160 has been reported as a paint of lower adhesion strength to ice than other paints.

d) S-2103 and S-2104 (Hempel)

Both coatings are experimental ice-phobic paints based on a modified acrylic resin. The S-2103 is a bluish black semi-gloss and the S-2104 is flat grey. The latter has a substantial quantity of graphite. The dark colours were chosen in accordance with a common view that sunshine can play some role in detachment of the ice.

e) Baysilone VP AC3323 (Bayer AG)

This silopren coating has been developed in collaboration with Marinteck (Norwegian Marine Technology Research Institute A/S) and tested in Norway. Good anti-icing properties were reported as well as outstanding resistance to weathering and ultra-violet degradation. The paint is clear and its density is 1.03 to 1.05 g/cm^3, considerably higher than other ice phobic coatings.

f) Thane 547 (Futura Coatings Inc.)

This coating is a two component aromatic urethane elastomer with outstanding abrasion resistance. It has been developed for railroad coal cars that have problems with frozen coal sticking to the sides of them. Because the Thane 547 is formulated with a PTFE polymer to provide greater slip and abrasion resistance, the producer claims that may considerably assist ice release.

g) Intersick (International Paints)

This is a silicone type coating developed in the U.S. as a result of the research for a non-toxic antifouling coating for cooling water intakes to power stations. The clear soft paint can be applied as a top coat on most of the common substrates.

From these eight paints, six were finally obtained and used in the experiments. The paints not received were Vellox 140 and Thane 547. The Vellox 140 was obtained after the tests were completed. The Technical Research Centre of Finland (VTT) reported that this material was tested in their laboratory and its adhesion strength to ice was found to be lower than that of ordinary paints, but not lower than that of polymer coatings.

Consequently, the following paints were selected for the experiments:

- Defro S-III (Kansai)
- S-2103 (Hempel)
- S-2104 (Hempel)
- Baysilone Vp AC3323 (Bayer AG)
- Intersick (International Paints)
- Inerta 160 (International Paints)

2.1.2 Laboratory Tests

As an initial test of the selected coatings, and a base coating of conventional exposed superstructure paint (Interlac) a series of laboratory experiments were completed. These were (a) an Ice Adhesion Strength Test, (b) an Abrasion Resistance Test and, (c) an Impact Test.

a) Ice Adhesion Strength Test

Ice adhesion strength tests were performed in the Fleet System cold chamber laboratory in Kanata. The procedure followed by the Arctec engineers is described below.

- Seven steel test plates, 800 x 90 mm, 6 mm thick, coated with different paints were delivered to the cold chamber, together with 35 steel rings 1/2" high, cut from 3", schedule 80 pipe.

- A test bench was outfitted with a hydraulic actuator, a stain gauge load cell and a strip chart recorder.

- All test plates were washed using a mild detergent, then rinsed with water and placed in the cold room.

- Any excess paint was removed from the contact area of the steel test rings and the contact area was coated with vaseline.

- Five rings were placed on each test plate.

- The sample surface around each ring was shielded from spray using a thin plastic shield, as illustrated in Figure 2.1.

- All samples were sprayed repeatedly with a solution of 3 percent NaCl until the rings were half filled. Thin layers of solution were added until the rings were finally filled. A spray applicator was used to produce fine droplets. The saline solution was sprayed and added at a temperature of -1°C.

- Once full, the samples remained in the cold room overnight to stabilize, as illustrated in Figure 2.2.

- Tests were conducted at a temperature of -10°C.

- The load was applied using a hydraulic actuator and the force measured by a strain gauged load sensor illustrated in Figure 2.3.

- The force/time history was recorded on a strip chart recorder.

The initial test, using a 3 percent saline solution was unsuccessful - the test specimens had very little adhesion strength. It was decided to repeat the tests and to conduct some additional tests. These tests were conducted with fresh water, eliminating one source of uncertainty.

FIGURE 2.1

ICE ADHESION STRENGTH TESTS
(Plastic shield around ring)

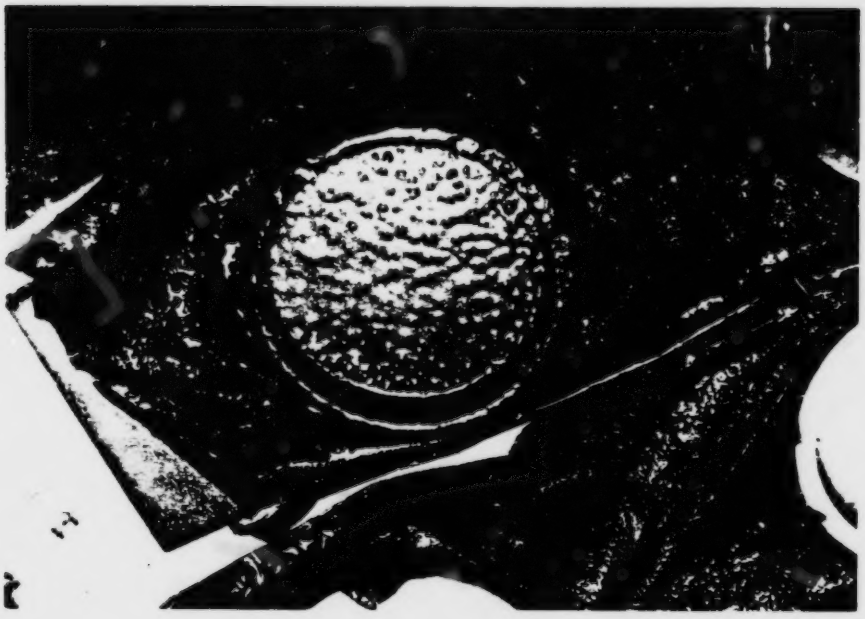
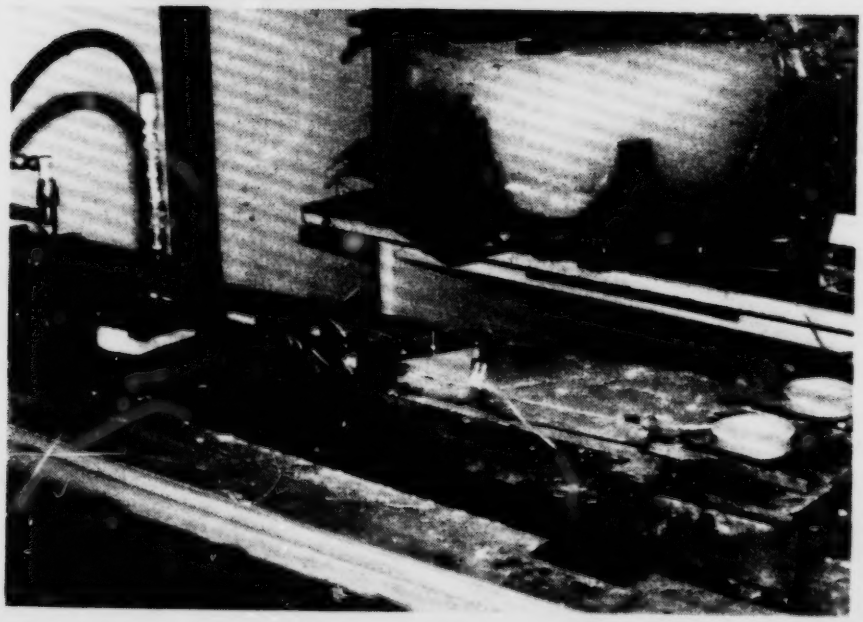


FIGURE 2.2

ICE ADHESION STRENGTH TEST
(Specimen prepared for measurements)

FIGURE 2.3

ICE ADHESION STRENGTH TESTS
(View of test bench)



To establish a base case, tests were conducted on a bare steel plate. Thus, the results could be checked against published values. For these tests, a number of different rings were used (plastic, steel rings, PVC, thin metal). The most successful tests occurred when using the PVC rings, where an average value of 3,459 kPa was measured. A further test was conducted using the Inerta 160 paint sample and the plastic rings. In this test, the surface was cleaned using Isopropyl alcohol. These tests showed values of adhesion in the range of 1,000 kPa.

Based on these results it was decided to conduct a full set of tests using the seven painted test specimens cleaned with Isopropyl alcohol an using PVC rings. In the case of Baysilone, the Isopropyl appeared to affect the coating - so a light ammonia solution was used. Tests were also conducted again on the bare steel specimen as a base case.

The tests were conducted in the same manner as described above but spraying fresh water at a temperature of 0.5°C. These tests provided more satisfactory results - summarized in Table 2.1.

For all painted test samples, the failure mechanism was a loss of adhesion at the ice/surface interface, leaving the painted surface ice free. For the bare steel, failure occurred in the ice near the ice/steel interface. In three cases, each on a different test specimen, there was virtually zero adhesion. The reason for this is unclear since all samples were prepared in the same manner.

In calculating the shear strength, the contact area used was $0.0011 m^2$ - the inside area of the test ring. Virtually no ice was found between the under side of the ring and the painted surface. The results are shown in Table 2.1 and Figure 2.4.

The initial test failure and the large scatter in the ice removal force are not unusual. Most of the available ice adhesion studies emphasize difficulties in making reliable and comparable adhesive strength measurements even under highly controlled experimental conditions. Complications are attributed to a number of factors which may be classified as:

- Those relating to the mechanical properties of accreted ice, which in turn are determined by the conditions under which the ice is built up.

- Those relating to surface properties, such as roughness, porosity, wetability, cleanliness, surface energy of the material upon which the ice adheres, and the interface between materials.

It seems that the greatest influence on the test results was the process used to clean the plates, the intensity of which was limited by the paints resistance to cleaning solvents. However, ideal cleanliness would not be present on board ship and, although not ideal, these tests can be considered a reasonable evaluation tool.

TABLE 2.1

ICE ADHESION STRENGTH TEST RESULTS

(Area of tests samples 0.0011 square meters)

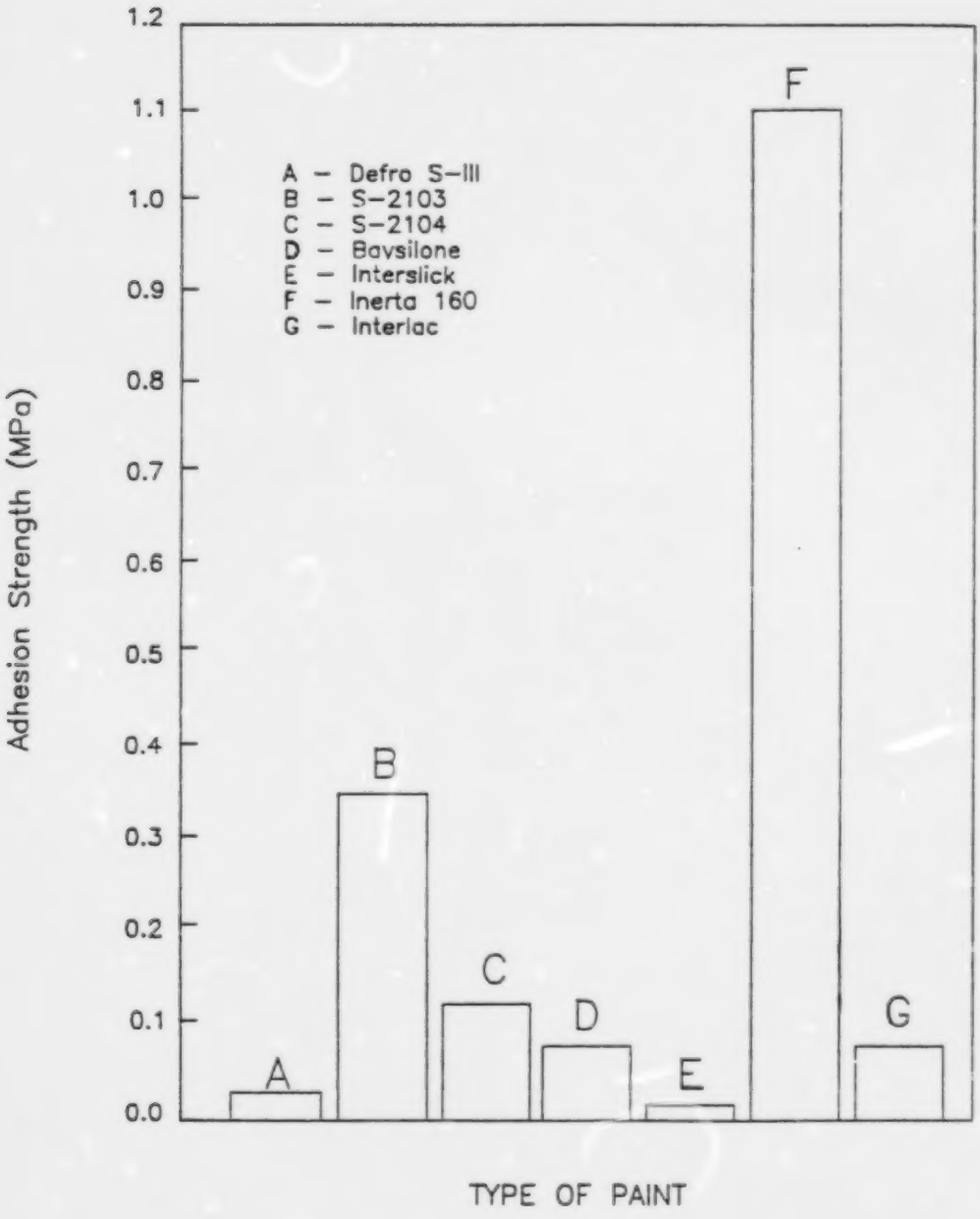
COATING	FORCE REQUIRED TO SHEAR SAMPLE (N)					AVERAGE SHEARFORCE (N)	STANDARD DEVIATION IN SHEARFORCE	ADHESION SHEAR STRENGTH (kPa)	STANDARD DEVIATION IN ADHESION SHEAR
	1	2	3	4	5				
Bare Steel (* 1)	3688	4076	3649	3300	4309	3804	352	3459	320
Inerta	1126	776	1670	0(*2)	1126	1175	320	1068	291
Interlack	136	117	41	164	45	101	49	91	45
Hempel S-2104	253	63	179	0(*2)	45	135	85	123	78
Hempel S-2103	263	625	224	168	632	382	203	348	185
Defro S III	35	14	0(*2)	23	39	28	10	25	9
Interslick	10	8	10	8	14	10	2	9	2
Baysilone	81	75	58	123	53	78	25	71	23

Notes: 1) Shear failure occured in the ice near the ice-steel interface
2) No adhesion of ice to the paint sample and not included in averages

Fresh water ice at $-10^{o}C$

FIGURE 2.4

ICE ADHESION TEST RESULTS



Fresh water ice at –10 Deg.C

b) Abrasion Resistance Test

This test was based upon the ASTM Standard No. D968-81 under the title "Standard Test Methods for Abrasion Resistance of Organic Coatings by the Falling Abrasive Tester". Two similar test methods are covered by this standard. One is based on natural silica sand from the specific sandstone deposits in the U.S. and the other is based on No. 16 grade silicone carbide (SiC). This second method was used.

The abrasive was allowed to fall from a specified height, through a guide tube onto a coated test plate until a certain amount of paint was worn away. The amount of abrasive in litres, divided by the loss of paint thickness in millimeters, reported as the abrasion resistance of the coating. This method has been used in the past for the rating of coatings for ship's decks.

The test apparatus, consisting of a funnel and guide tube, firmly supported in the vertical position, is shown in Figures 2.5 and 2.6. The procedure includes marking off 25 mm diameter circular areas on the test plates, positioning these areas under the guide tube at a 45° inclination, pouring abrasive (measured volumetrically) into the funnel and measuring the thickness of the plate in the abraded area before and after the test. The thickness measurements were done, as recommended in the Standard, by means of a micrometer.

The results are shown in Figure 2.7. Figure 2.8 illustrate the abraded spots on each plate. Photographs of all plates are provided in Appendix 2.

Although results obtained by different laboratories may be scattered, due to at least 19 degrees of freedom, the test is regarded by the ASTM as quite accurate if used for ranking the coatings by magnitude of abrasion resistance. However, while the results were acceptable for most of the paints, the abrasion resistance of Interslick was found to be too high. It resembled a soft rubber and apparently had a higher modulus of elasticity than any other paint. This property resulted in very effective rebounding of the abrasive particles rather than scratching. However, if higher force was applied, for example scratching with a nail, then the surface of the paint was damaged very easily. The other silicone type paints likely had a lower modulus of elasticity so the rebounding of particles was not observed and the surfaces were finally destroyed by the falling abrasive. Because of 2.14 present the effects of 20 fingernail scratches done on the softer paints. It is clearly seen that the Interslick, although showing considerable resistance to damage by falling abrasive, is completely intolerant to the softest scratching. The other paints faired much better in that test.

c) Impact Test

Looking at the mechanism of paint destruction by falling abrasives, it could be concluded that the falling particles develop impacts on the specimen and thus the abrasion test could be considered as an impact test. However, it was decided to do an impact test by employing very simple methods, the result of which would be a photographic record allowing comparison of damage patterns on the tested paints.

FIGURE 2.5

DESIGN DETAILS OF
ABRASION TEST APPARATUS

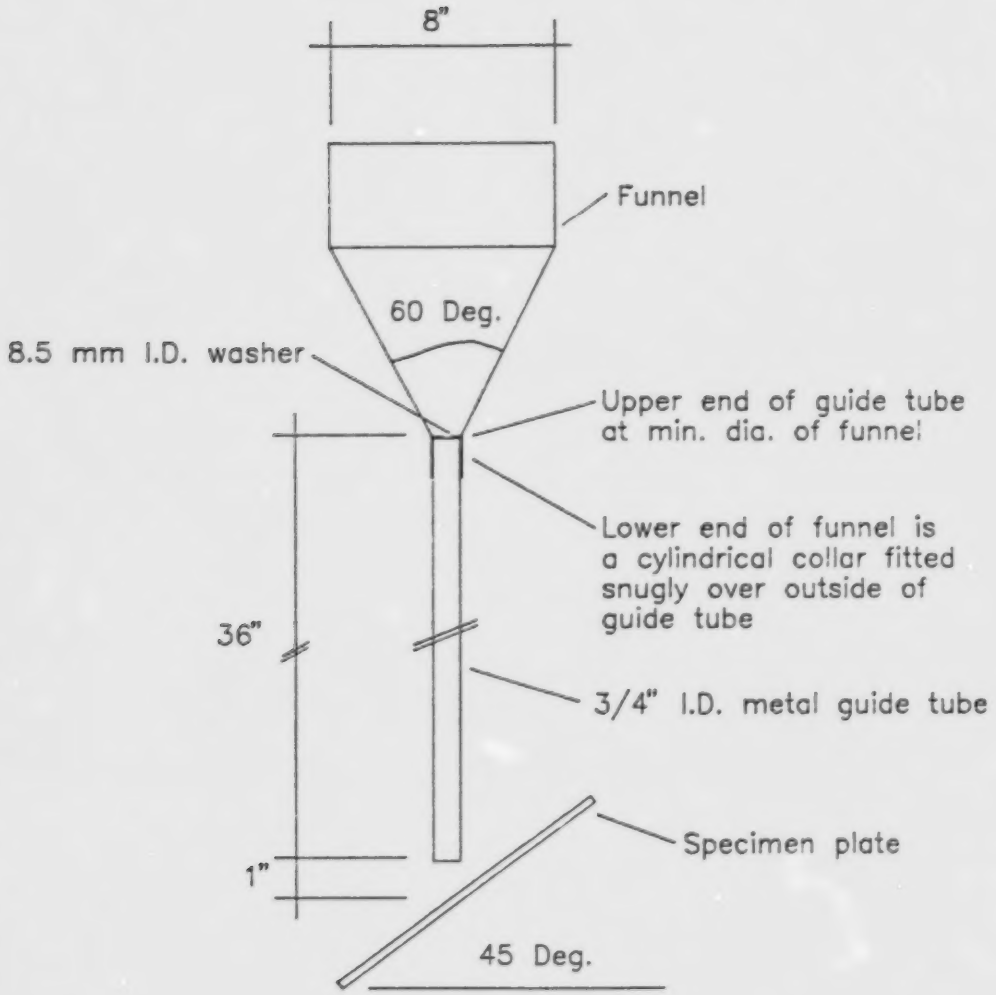
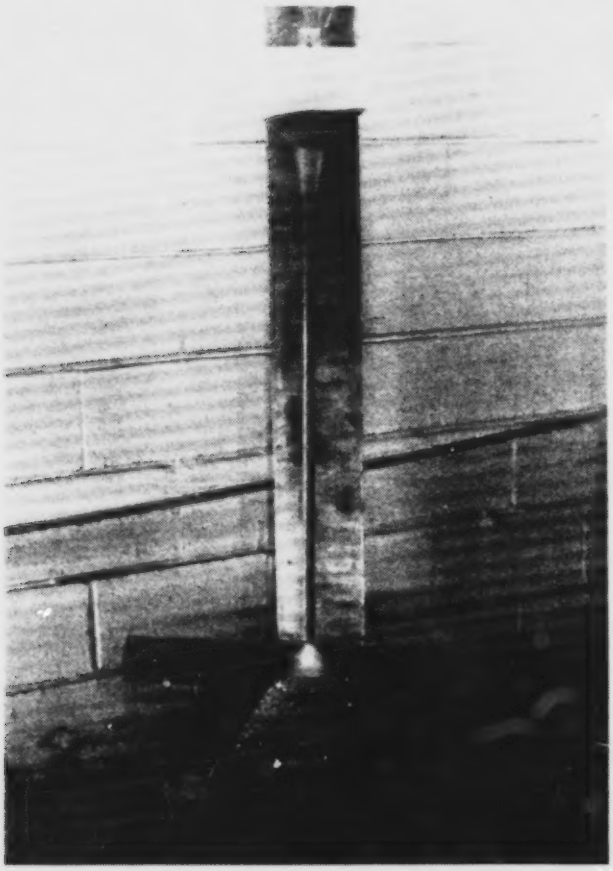
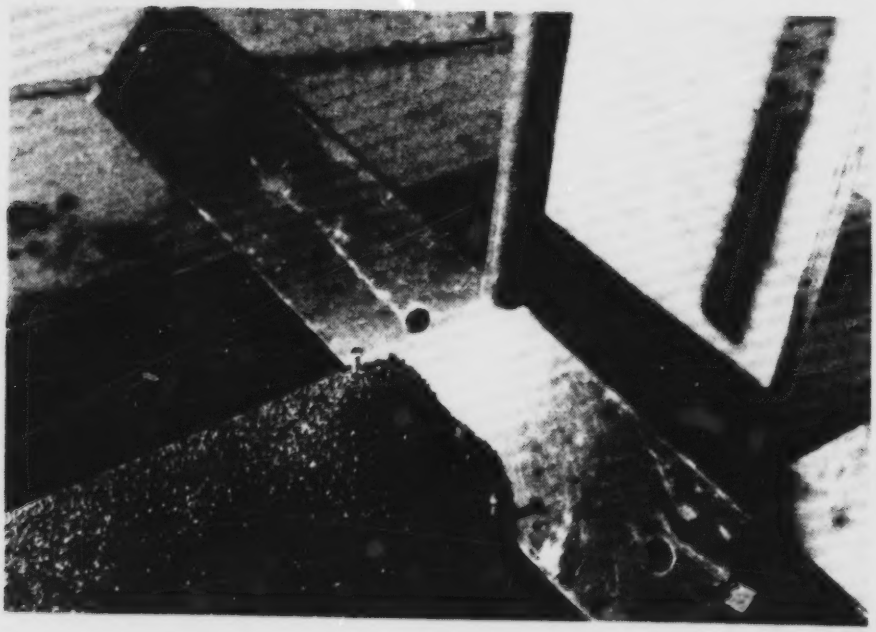

8"
Funnel
60 Deg.
8.5 mm I.D. washer
Upper end of guide tube at min. dia. of funnel
Lower end of funnel is a cylindrical collar fitted snugly over outside of guide tube
36"
3/4" I.D. metal guide tube
Specimen plate
1"
45 Deg.

FIGURE 2.6

ARRANGEMENT OF ABRASION RESISTANCE TEST



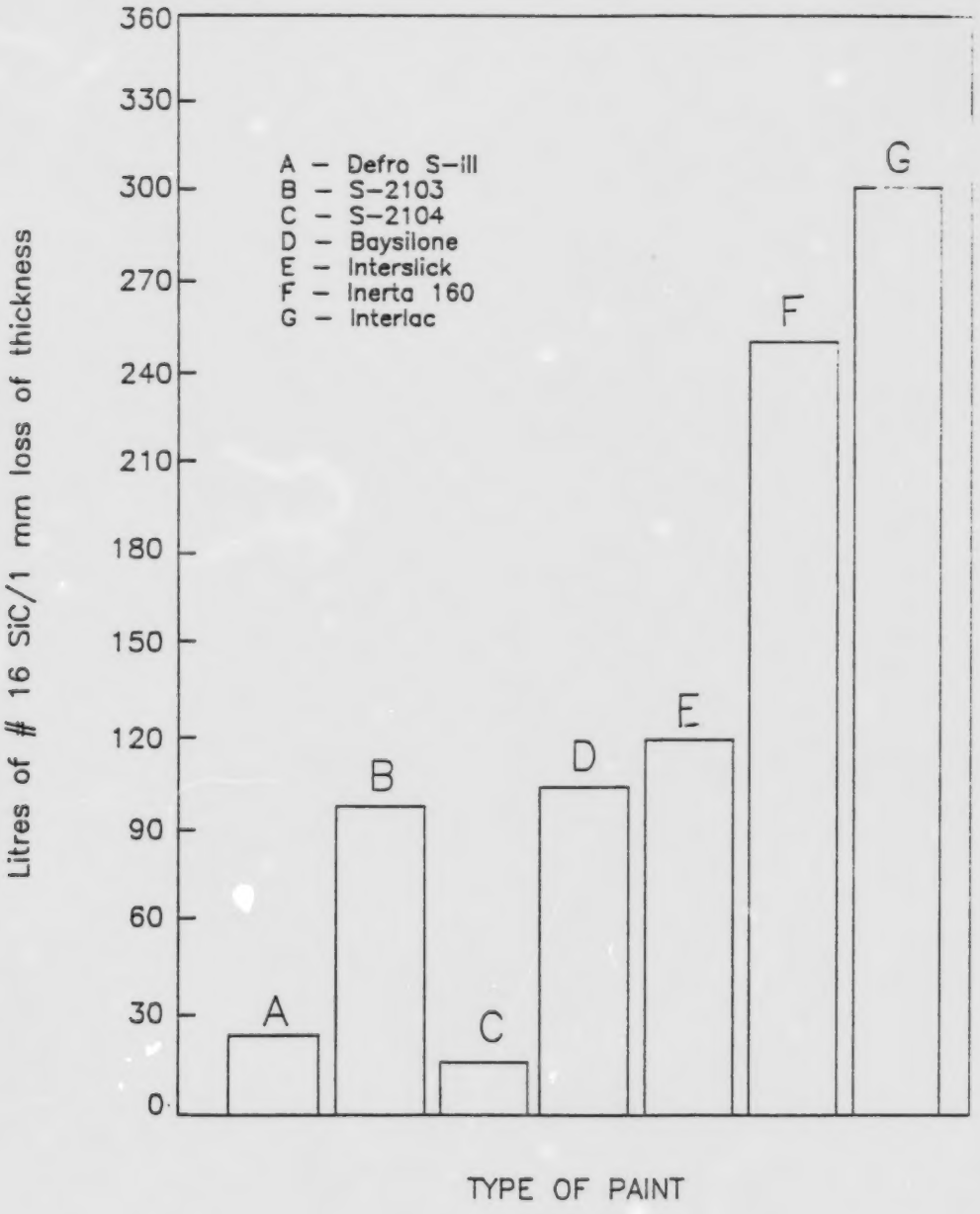
Arrangement of the Apparatus



Arrangement at lower end of tube

FIGURE 2.7

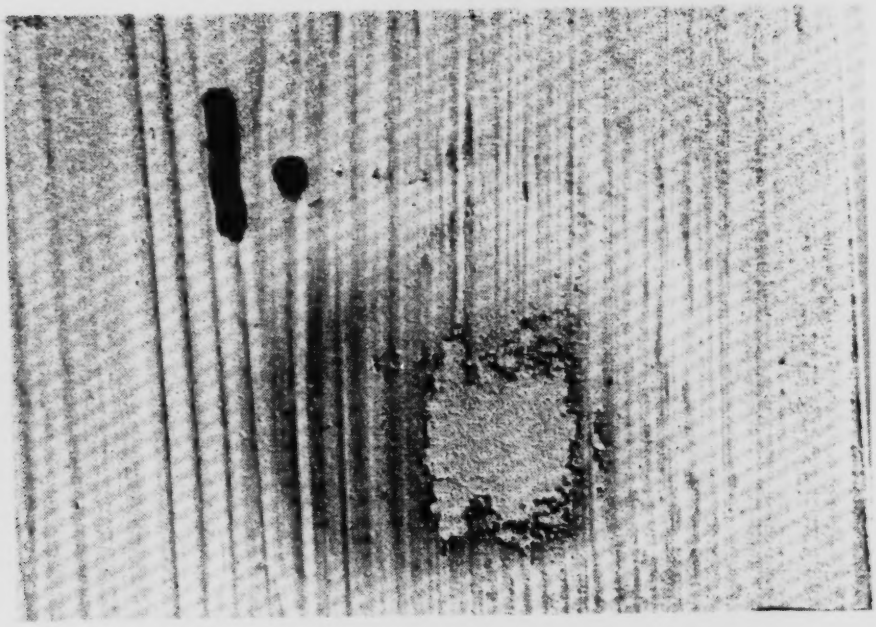
ABRASION RESISTANCE OF SELECTED PAINTS



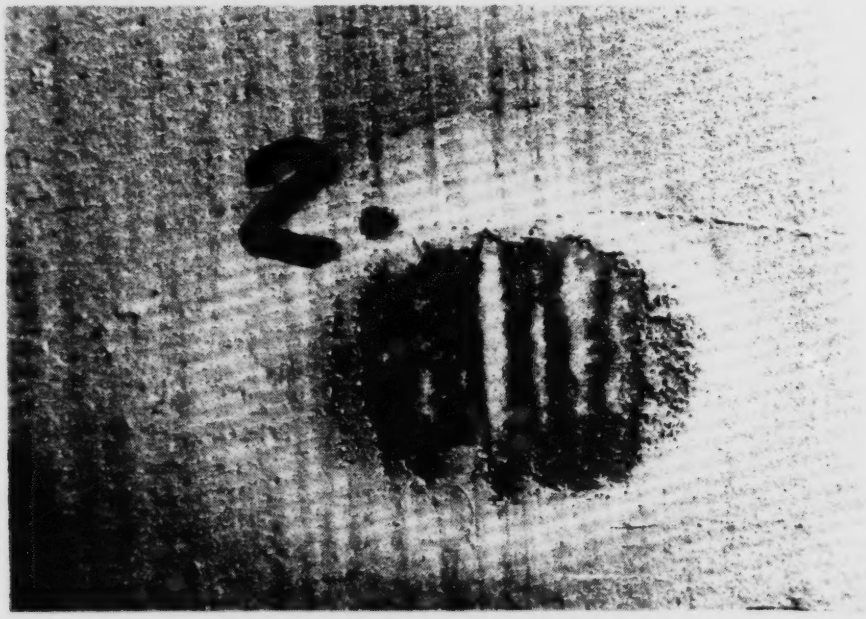
By falling abrasive tester – ASTM D968

FIGURE 2.8

ABRASION RESISTANCE TEST



Baysilone



Defro S-111

A two pound hammer, with a pivot on the free end of its handle, was allowed to fall by its own weight from the vertical position. The hammer and the marks left on various surfaces are illustrated on Figure 2.9. Photographs of all plates are provided in Appendix 2. It can be seen that the marks within each plate look alike, which offers some evidence that the repeatability of this method is good. Based on these photographs:

- The ice phobic paints exhibited good adhesion to the substrate, in comparison with the standard marine paint (Interslick),
- Among the silicone type coatings, Baysilone suffered the least damage,
- The test performed on Interslick confirmed high elasticity but could not demonstrated a lack of resistance to scratching,
- Both Hempel paints showed similar soft consistency and good adhesion.
- Inerta 160 appeared to be superior to the standard marine paint since, despite a microscopic indentation, its surface remained intact.

2.2 Electrical Heat Tracing

Thermal methods of de-icing and anti-icing are more effective than application of chemicals of ice phobic paints. Among them, the electrical heating of outer surfaces is an uncomplicated method but usually considered too expensive, especially for large areas, due to high installation costs and energy consumption. However, for small items or inaccessible areas this method is very attractive.

Electrical heat tracing may be used for either anti-icing or de-icing purposes. In the first case, the temperature of the protected surface is kept high enough to prevent water droplets from freezing on impact. In the other case, the treated surface is allowed to be covered with ice to a certain thickness and then the heater is switched on and the ice adjacent to the surface is melted, braking its adhesion and allowing removal by gravity or mechanical methods. The de-icing method is more efficient because the insulating effect of a layer of accreted ice reduces the power requirement by 20 to 50 percent.

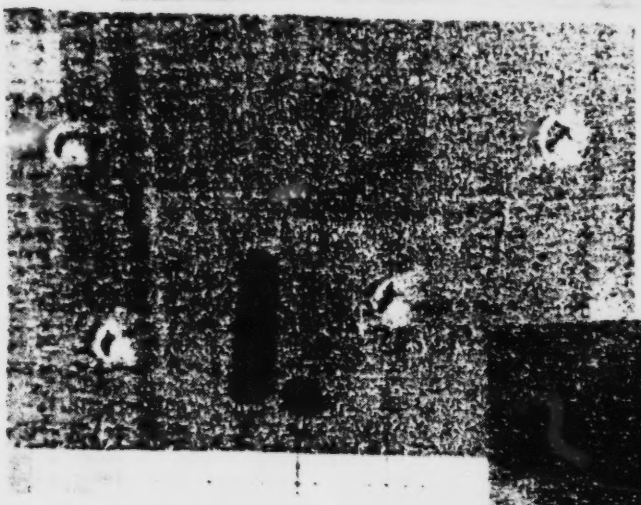
Most of the available literature on the use of electrical heaters for anti-icing or de-icing applies to oil rigs. However, data contained in those publications is equally applicable to self-propelled ships.

The main consideration in designing a heat tracing system is to determine the required heat load, as a function of:

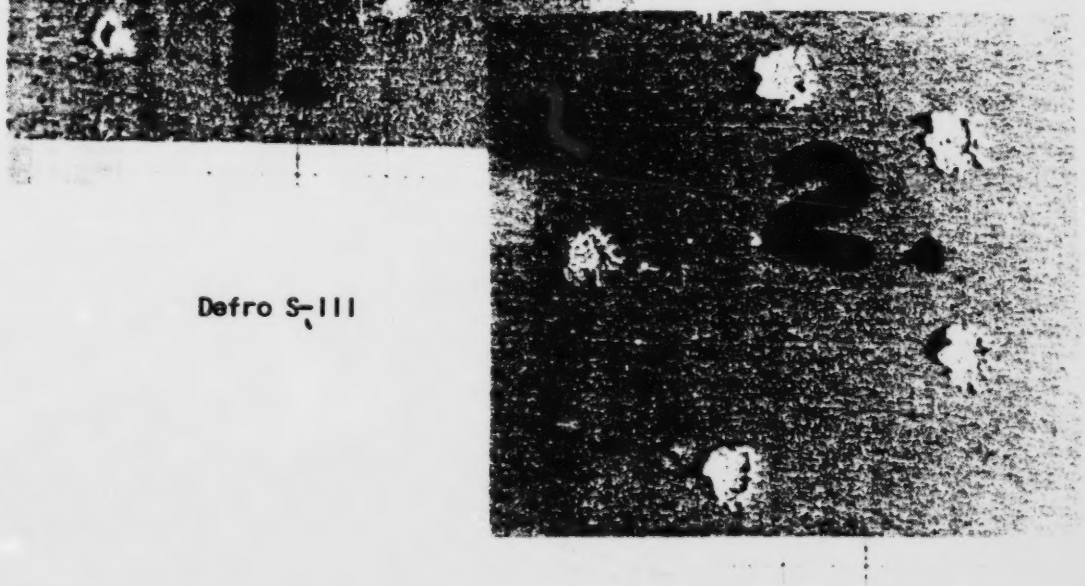
- air and sea temperatures,
- wind speed and direction,

FIGURE 2.9

ARRANGEMENT OF IMPACT TEST



Baysilone



Defro S-111

- icing rate,
- water salinity,
- location and material of the treated surface.

From the literature containing analytical and experimental data it is possible to assess the heat load at various conditions. For example, Figure 2.10, derived by Raychem Corporation from calculations and laboratory tests, shows power requirements for anti-icing of a helideck and de-icing of an oil rig bottom deck. In general, assuming environmental conditions of -20°C ambient air temperature and 20 m/s wind speed, typical anti-icing values range between 5600 to 1,100 W/m^2 for open areas, while doors and hatches require 120 to 140 W/m around their circumference. The power requirement for de-icing ranges between 300 to 550 W/m^2.

A variety of electrical heat tracing equipment exists. They can be divided into two major groups:

- Self-regulating heaters have been developed in recent years due to significant progress in heater technology and materials, and have become the most popular type for pipe heat tracing. Their principal advantage is the ability to decrease the power output as the temperature increases. This eliminates a major failure mode of electrical heaters destroying the electrical insulation with their own heat output.

  These heaters were found especially suitable for anti-icing and de-icing applications because of the limit of temperature which could be reached, even if left on in a warm environment. This also eliminated the possibility of personnel being burned from contact with the heated surface.

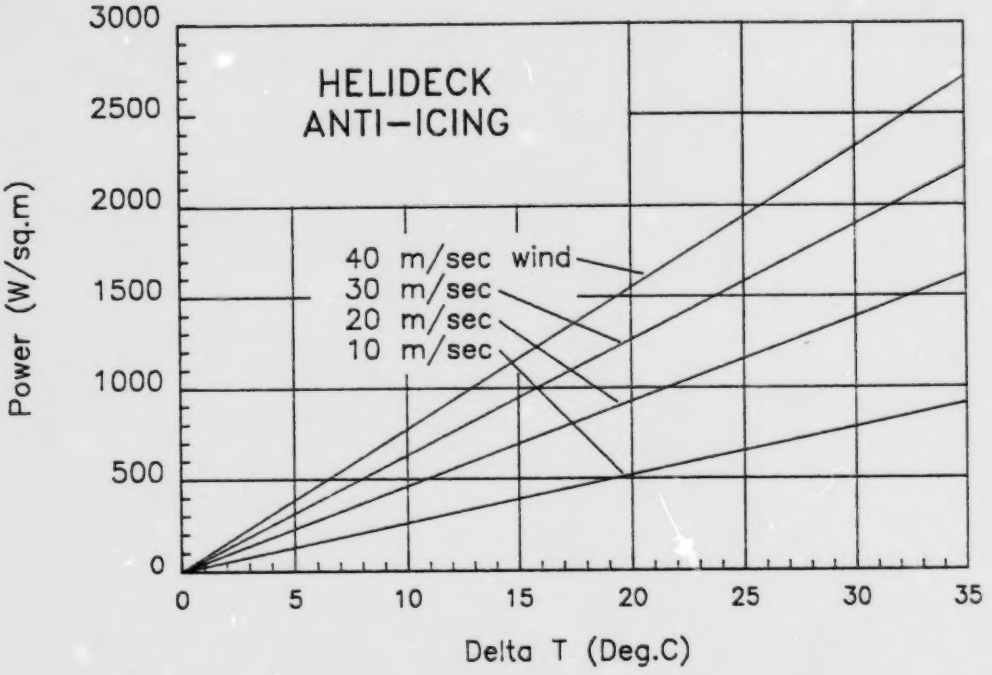
- Non self-regulating heaters are still used, but in some applications their use is restricted by safety regulations. For example, it is reported that all known anti-icing heat tracing systems on oil rigs are of the self-regulating type, because Norwegian offshore regulations limit the heat output of non-self-regulating heaters to 100 W/m^2 or less, which is insufficient for most applications.

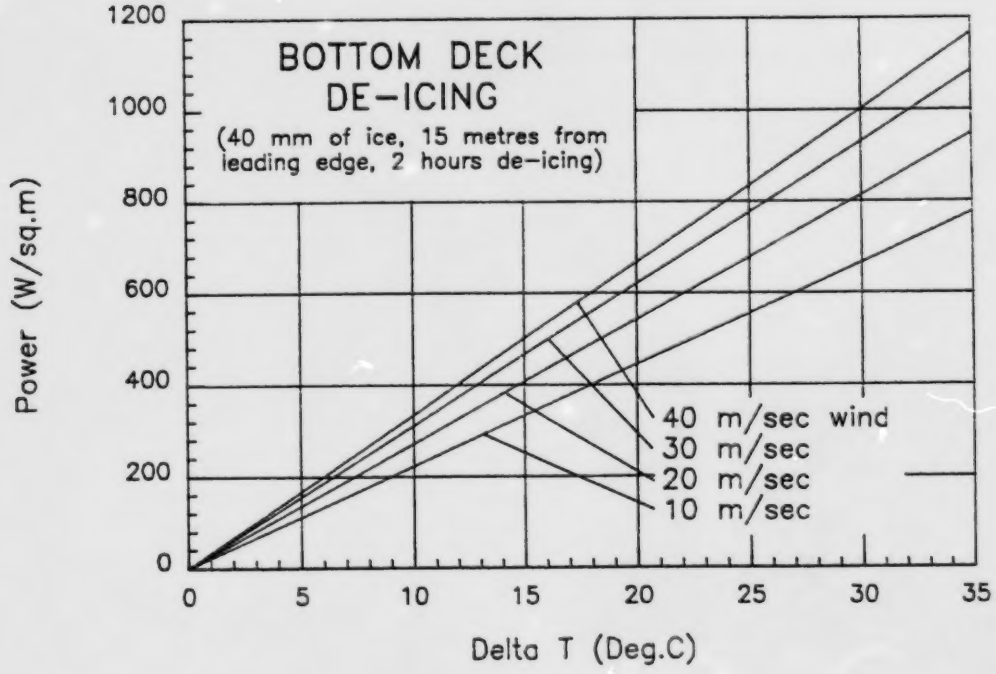
For selection of the most suitable heaters for this project, several manufacturers and numerous scientific and ship safety authorities were contacted. A full list of contacts is attached in Appendix 1. One of the most experienced was Raychem Corporation in the United States, which specializes in the development of self-regulating heating tapes.

The tape is an electrical cable consisting of two parallel electrodes between which there is a temperature sensitive core made of specially blended polymers and current conducting carbon. At low temperatures, the carbon particles are close together allowing electrical current to flow through the core from one electrode to the other, which in turn generates heat. As the temperature rises, the core material expands and disrupts the carbon network, increasing electrical resistance, reducing current flow and decreasing heat output. The continuous process occurs automatically and

FIGURE 2.10

POWER REQUIREMENT FOR ANTI-ICING AND DE-ICING





independently at each point between the electrodes.

It was decided to chose one of the Raychem self-regulating heaters for experiments on the 'CAPE ROGER'.

The other manufacturer whose product was selected for experiments is Electrothermal Engineering of the United Kingdom. This company is currently involved in icing control systems for deck and structure mounted equipment for a major contractor to the Royal Navy. They offered a heater in the form of a flat flexible mat, rather than a tape.

The flexible rubber mat heater consists of an element winding, sandwiched between two sheets of silicone rubber cloth, which is then heat cured under pressure to form an integral heater. According to the manufacturer, the waterproof mat heaters can be made in any shape or size, with a normal maximum size of 43 x 124 cm. The windings are designed to ensure uniform heating over the whole area. Because the heaters are of low mass with a thickness of about 2.5 mm, the time required to reach working temperature is short and power consumption is curtailed. Although the mat heaters are not of the self-regulating type, the manufacturer advised that, for anti-icing purposes, it was not required to control the temperature of the heater with a thermostat because the heater could withstand up to 210°C on the surface of the rubber. The only protection required was a lamp indicating that the heater was in operation.

2.3 Air Guns

This experiment was proposed with the intention of finding a mechanical substitute to wooden mallets, which are presently used on ships for manual de-icing. It was expected that a suitable pneumatic tool would be more convenient to use and safer than conventional mallets, and the ship structure and deck equipment would be less exposed to destructive blows.

Only two reports were found on the use of pneumatic tools for de-icing. Japanese researchers reported that air hammers could brake up large quantities of ice while causing less damage to bulwarks and decks than the standards methods, provided that the proper rounded tips were used. They also claimed that air hammers could be safely operated at sea on the open deck. The other report mentioned that a U.S. fishing company, Westward Trawlers, which operate their vessels in the Gulf of Alaska, use air hammers for de-icing.

Through contacts with various manufacturers of pneumatic tools, listed in Appendix 1, an overview was completed of tools being considered for de-icing.

2.4 Inflatable Panels

One of the most effective de-icers is probably a rubber tube or series of tubes built into a rubber mat attached to the ship structure, such that, when the tubes are inflated with air they expand and the mat surface breaks the adhesion of ice to the mat surface. This type of icing control device

is referred to in literature as the inflatable panel or pneumatic de-icer.

The inflatable panels were originally developed for removing ice from the leading edges of aircraft wings and, in recent years, their application has been extended to marine use.

The first known marine application was developed in the United Kingdom as a result of the loss of two British trawlers during the winter of 1967/68. Palmer Aero Products Ltd., a division of BTR Industries, modified their existing aircraft pneumatic de-icers and tested them initially at a scale of 2:1 in a cold chamber and then in 1968 at full scale on board the British trawler 'BOSTON PHANTOM'. More panels were installed on the same trawler and successfully tested during a normal fishing voyage to Iceland in January 1969.

- The panels consisted of external rubberized fabric covers and internal rubber tubes through which air was passed in intermittent pulses to break ice adhering to the surface.

- The panels were fitted in the locations shown in Figure 2.11, i.e. to the bipod mast, stays, bridge front, part of the whale back and the face of the radar scanner. The controls for these were situated on the bridge.

- De-icers with an average size of one square metre were mounted on the bridge front up to the windows. It was reported that the size of the panels was restricted due to the possibility of punctures to the air tubes. However, these could be easily repaired and the fear of damage appeared to be exaggerated.

- The materials used were natural rubber for the internal tubes and, nylon fabric coated mainly with natural rubber for the external covers. To improve their weathering properties, the top layers of those coatings were made of newprene. Accurated data on properties and thickness of those materials could not be obtained.

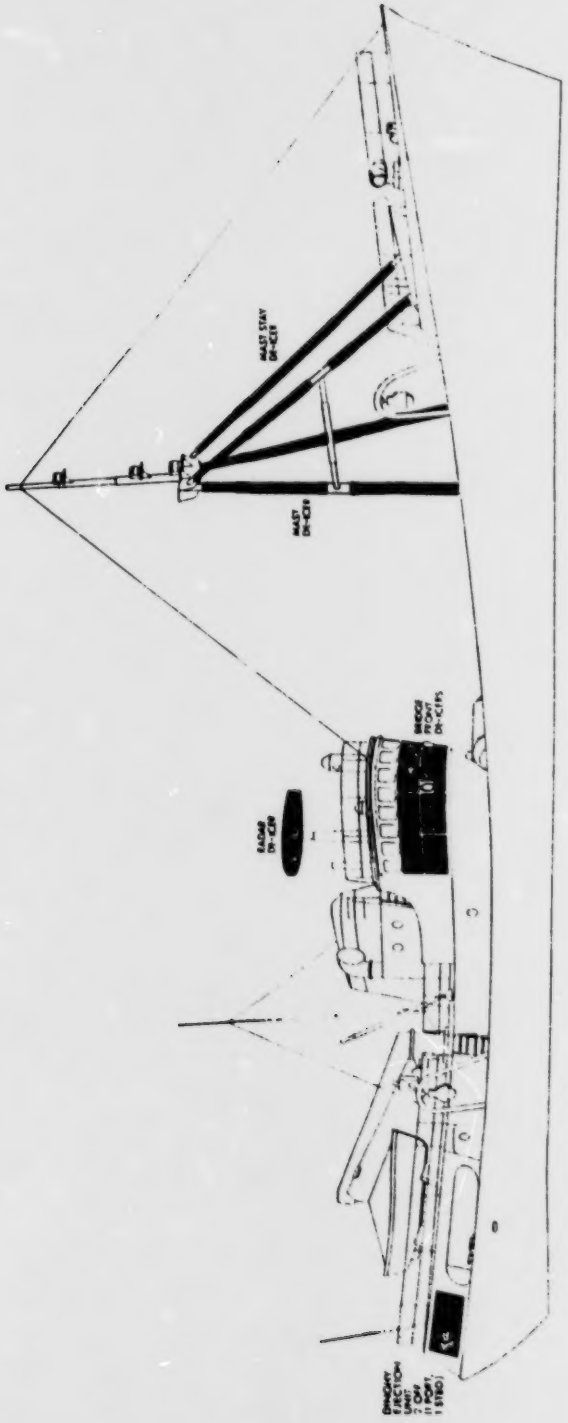
- All of the panels were connected to a compress air system through a reduction valve which was set for working pressure of 15 p.s.i. The inflation system was activated manually from the control panel on the bridge.

- Severe icing conditions were experience during the test voyage with an estimated accumulation of ice of 2.5 tonnes per hour. The rate of ice build up on the rubber surfaces of the de-icers appeared to be the same as for metal surfaces. Ice was allowed to build up on the bridge de-icers to a thickness of about 12 mm before inflation. When it broke away, the majority immediately flowed overboard in the wind. The remaining broken ice had a tendency to adhere to the panel.

- The panels were reported to be very successful. During the worst period of icing the vessel collected about seven tonnes

FIGURE 2.11

PNEUMATIC DE-ICING PANELS ON THE
'BOSTON PHANTOM'



of ice and it was later calculated that the weight of ice would have increased by another two tonnes if the inflatable panels had not been installed and used.

- Since the time of those tests no similar trials have been conducted in the U.K. because the British trawlers ceased to fish in waters around Iceland. Despite an extensive literature search and numerous contacts with maritime safety agencies, scientists and manufacturers involved in this field (see Appendix 1), it has not been possible to identify any other attempts to use pneumatic de-icers on ships, with the exception of some tests later carried out in Canada.

In 1970 Dr. J.R. Stallabrass, of the NRC Low Temperature Section, conducted several laboratory and outdoor tests evaluating a number of methods proposed for reducing the hazard of superstructure icing on ships. One of the methods included in his program was a pneumatic bulkhead de-icer which resembled the panels designed for the 'BOSTON PHANTOM'.

- The test panel measured 4 ft. by 3 ft. and could be used both for mast de-icing tests in the wind tunnel and, when mounted on a flat surface, for bridge front de-icing tests at the outdoor test stand. Details are shown on Figure 2.12.

- The outdoor test site comprised of a 20 ft. square, 3 ft. high platform on which test equipment was mounted. To simulate the icing spray a high capacity fan was used with spray nozzles mounted on its front face.

- The tests were conducted in 8 runs, each at a different temperature, amount of spray and cold-soak time. The air pressure used for inflation was 15 p.s.i.

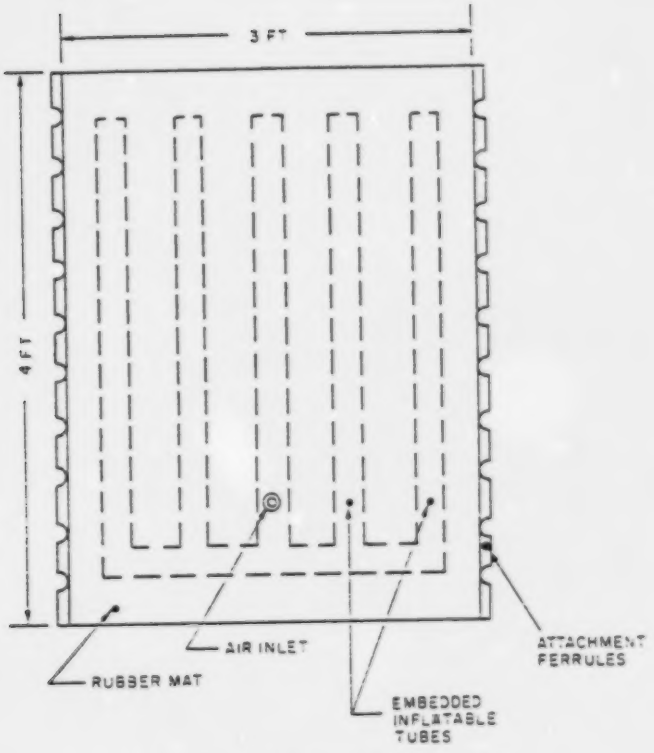
- When the ice thickness on the de-icer did not exceed 2 inches, the ice was always shed cleanly, regardless of the ambient temperature and nature of ice. However, when the thickness of ice was allowed to reach 4 inches and a long overnight cold-soak was applied before de-icing, it was necessary to inflate the panel three times before the ice was 90 percent removed. The first inflation cracked the ice, but it remained anchored and did not shed. A second inflation caused only a small amount of ice to break away, and the third inflation finally cleared most of the panel. That sample of ice had been created at -15°C and de-iced at -19°C.

Although those tests were unsuccessful, no firm conclusion or recommendations were given because the scientists expected to confirm their findings in an actual sea-going evaluation.

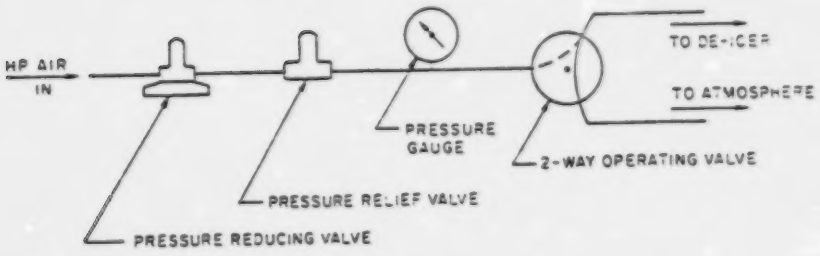
Several years later, in 1977, the 'FPV CAPE ROGER' was fitted with pneumatic panels across the front of the superstructure to a height of 3.6 m above the deck. However, the trials concluded with unsatisfactory results as the panels deteriorated rapidly, with pin holes appearing in the

FIGURE 2.12

DETAILS OF THE PNEUMATIC DE-ICER
TESTED AT THE NRC



(a) LAYOUT OF PNEUMATIC DE-ICER



(b) CONTROL GEAR

rubber material after a few inflations, causing loss of air. The panels were removed afterwards and no other action was taken. No reports were prepared to identify the design of the panels or their materials.

3. SHIPBOARD EXPERIMENTS

3.1 General

A series of shipboard tests were designed to assess the efficiency of each de-icing/anti-icing method. The 'CAPE ROGER' was used for:

- Ice Phobic Paint
- Heating Panels
- Air Hammer, and
- Inflatable Panels

and the 'ASL SANDERLING' was also used for ice phobic paint experiments. These ships were made available respectively by the Department of Fisheries and Oceans and, Atlantic Searoute Limited.

The equipment was arranged onboard each vessel as shown in Figures 3.1 and 3.2. All experiments on the 'CAPE ROGER' were mounted on the accommodation house front. On the 'ASL SANDERLING' the painted panels were mounted on the front of a house structure located near the bow.

Experiments were conducted during the months of February through March of 1988 and January through March of 1989 and, measurements and photographs of icing severity were taken where possible. These data are presented in this section.

3.2 Icing Incidents

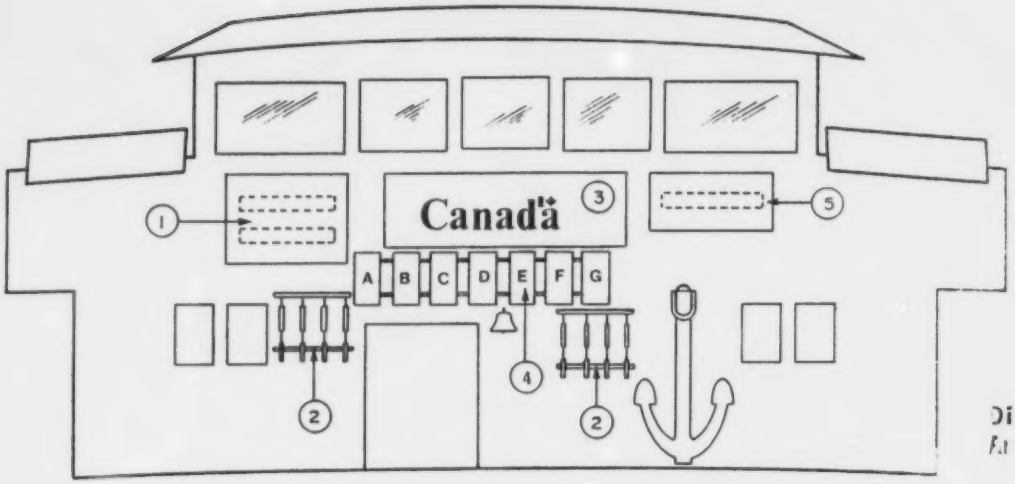
A list of the icing incidents which occurred during the winters of 1987/88 and 1988/89 is presented in Appendix 3. This list provides information on the following factors:

- Date
- Vessel name
- Commencement time and duration
- Ship's position
- Air and sea temperatures
- Wind speed and direction
- Sea state
- Precipitation
- Origin of the icing, and
- Severity of the icing

A tabulated summary of this data is shown in Table 3.1. It can be seen that the incidence of icing was infrequent and the severity was light. An example of the typical severity of these events is illustrated in the photographs in Figure 3.3. Although the number of incidents and the severity was less than anticipated, and is thought to be untypical of area, there was sufficient data collected for an assessment of all experiments except the Air Hammer.

FIGURE 3.1

TEST ARRANGEMENT ON THE 'FPV CAPE ROGER'



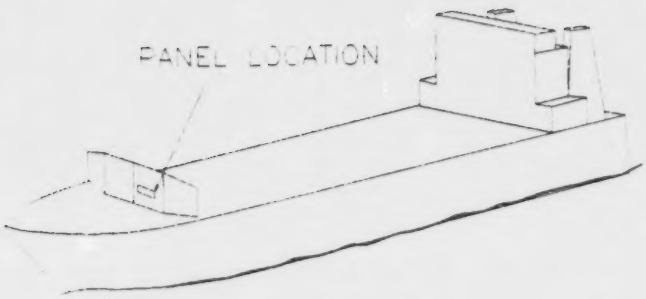
Diagramatic Arrangement

1. ELECTRICAL MAT HEATERS 1000 W/sq.m
2. CYLINDERS COATED WITH ICE PHOBIC PAINTS
3. ELECTRICAL HEAT TRACING TAPES
4. STEEL PLATES COATED WITH ICE PHOBIC PAINTS
5. ELECTRICAL MAT HEATER 800 W/sq.m

Installed Layout

FIGURE 3.2

TEST ARRANGEMENT ON THE 'ASL SANDERLING'



Panel Location

Installed Layout

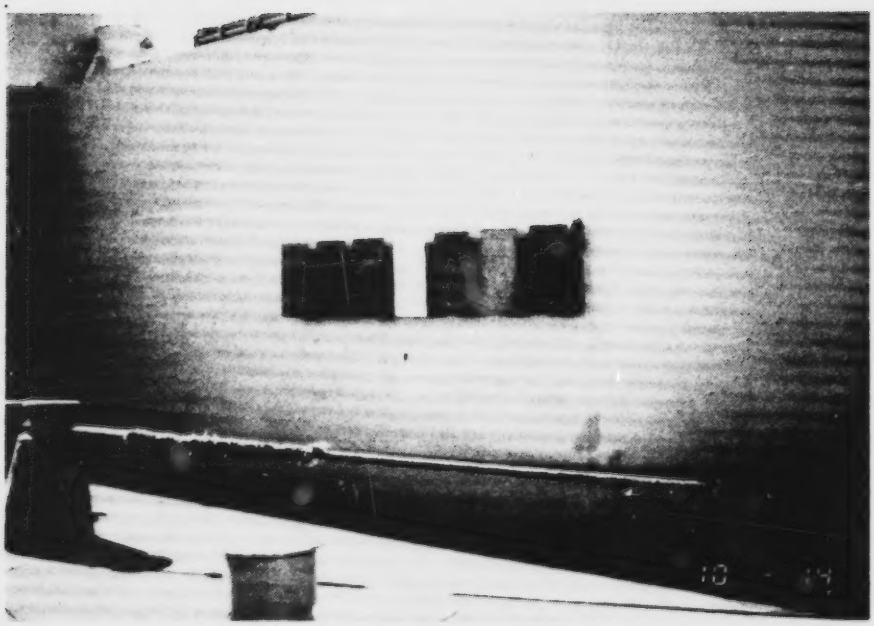


TABLE 3.1

SUMMARY OF ICING EVENTS

SUMMARY OF ICING INCIDENTS REPORTED: FEBRUARY - MARCH 1988

EVENT #	DATE	VESSEL	COMMENCEMENT AND DURATION	SHIP'S POSITION	SHIP'S HEADING AND SPEED	TEMPERATURES	WIND	SEA STATE	PRECIPITATION	ORIGIN OF ICING	SEVERITY OF ICING
1	26/02/88	CAPE ROGER	1230 2.5 hours	49° 57'W 46° 58'N	0° alt. to 320° 12.5 knots (avg.)	Air: -0.5°C Sea: -0.6°C	15 knots at 020° NE	nil, mod. swell	light	atmospheric	light
2	04/03/88	SANDERLING	2200 8 hours	Pier 36 Halifax Harbour		Air: -1°C Sea: N/A	11 to 16 knots		light	atmospheric	very light
3	14/03/88	CAPE ROGER	0400 4 hours	52° 57'W 43° 31'N	080° ENE 10.5 knots	Air: 0.0°C Sea: +3°C	10 to 15 knots at 290° NW	nil, light swell	moderate to heavy	atmospheric	light
4	16/02/88	CAPE ROGER	0100 2.5 hours	52° 30'W 47° 10'N	005° NNE (true) 5 knots	Air: 0.0°C Sea: +1.0°C	25 knots NE	moderate	light to moderate	icing	light
5	22/03/88		N/A overnight	56° 35'W 47° 15'N	236° WSW 10.2 knots	Air: -6°C Sea: +0.54°C	35 knots at 260° WSW	moderate	moderate	atmospheric and sea spray	moderate
6	12/01/89	CAPE ROGER	0900 1.5 hours	48° 24'W 46° 10'N	310° 3 knots	Air: -7°C Sea: 0.2°C	40 to 50 knots NW	15 to 20 feet	light snow	sea spray	light
7	14/01/89	CAPE ROGER	1000 4 hours	47° 55'W 46° 21'N	270° 6 knots	Air: -5°C Sea: 0.5°C	25 to 30 knots, 030°	3 to 6 feet	occassional snow	sea spray	very light
8	21/09/89	CAPE ROGER	1200 2 hours	52° 28'W 47° 15'N	180° 5 knots	Air: -1.5°C	30 knots changing from SE to SW	10 to 15 feet	occassional snow	sea spray + atmospheric	light
9	22/01/89	CAPE ROGER	0800 3 hours	52° 28'W 47° 20'N	360° 4 knots	Air: -4.5°C Sea: 0°C	60 to 70 knots NWN	10 to 15 feet	none	sea spray	light
10	27/01/89	CAPE ROGER	1400 2.5 hours	52° 50'W 50° 45'N	360° 4 knots	Air: -1°C dropping Sea: -1°C	60 knots	20 to 25 feet	occassional snow	sea spray	light
11	02/02/89	CAPE ROGER	0300 6 to 8 hours	52° 21'W 48° 30'N to 52° 52'W 49° 0'N	360° 6.5 knots	Air: -6.5°C	30 knots	moderate NW	none	sea spray	light
12	17/02/89	CAPE ROGER	1915 10 hours	49° 03'W 45° 14'N	275° 3 to 4 knots	Air: -7°C Sea: 0	43 to 50 knots, 270°	approx. 20 feet	moderate to heavy	sea spray	moderate
13	28/02/89	CAPE ROGER	0900 22 hours	48° 20'W 47° 30'N	270° 10 to 15 knots	Air: -1°C to -3°C Sea: 1.2°C	35 to 40 knots, 270°	7 to 14 feet	fog and snow	atmospheric and sea spray	light

FIGURE 3.3

PHOTOGRAPHS OF TYPICAL ICING EVENTS

January 4th, 1989
St. John's Harbour

January 4th, 1989
St. John's Harbour

February 18th, 1989
At sea

3.3 Experiments

Experiments were designed, installed and completed on two ships - the 'CAPE ROGER' out of St. John's and the 'ASL SANDERLING' out of Halifax. Those experiments were:

CAPE ROGER - Ice phobic paints
- Heat tracing
- Air hammer
- Inflatable panels

SANDERLING - Ice phobic paints

The design and results of these experiments will be reviewed in this section and discussed in section 4. A set of instructions were prepared to assist the project engineers in monitoring the experiments on board ship. These are attached as Appendix 4.

In general, the 1988 and 89 icing seasons were very mild. Only thirteen icing events were recorded and of these, only a few were of any consequence. Nevertheless, there was sufficient icing to make a minimal evaluation of all experiments except the Air Hammer - there was simply insufficient ice for removal by that means. The arrangement of each experiment and the results are presented in the remainder of this section.

3.3.1 Ice Phobic Paints

a) Arrangement of the Experiment

This experiment was arranged on the 'CAPE ROGER' and 'ASL SANDERLING' as shown on Figures 3.1 and 3.2. The paints tested were, from left to right:

A - Baysilone
B - Hempel S-2103
C - Intersilck
D - Interlac
E - Defro S-III
F - Hempel S-2104
G - Inerta 160

The paints were applied on an undercoat to the plate panels and cylinders, before mounting on the ships. On the 'CAPE ROGER' the panels and cylinders were located on the accommodation house front, about 2 metres above the main deck and astride the centreline. On the 'SANDERLING' the panels were mounted on the front of a house on the foredeck, about 2 metres above the deck.

The position was arranged to allow the panels and cylinders to be easily inspected and photographed and, in the case of the cylinders, removed for weighing.

The panels were installed during January 1988 and were exposed to the environment until their removal in March 1989. The panels were monitored (a) throughout the 1988 icing season (January to March), (b) later in the year (after eight months of weathering) and (c) during the 1989 icing season (January to March).

b) Results

The data which was collected takes the form of observations, measurements and photographs. The observations and measurements are tabulated in Tables 3.2 and 3.3. A selection of photographs taken during icing incidents are attached as Appendix 5 and two examples are shown in Figure 3.4.

Although the icing was insufficient to be conclusive, some observations can be made on the performance which was observed from each paint/coating.

Baysilone

- At temperatures around freezing, ice and snow did not adhere to the test plate.
- At lower temperatures, icing was initially appearing in the form of beads, eventually covering the surface with ice to the same extent as on the other plates.
- Mechanical removal of the accreted ice was considerably easier than from the non-silicone paints.
- Good hydrophobic properties were retained after a year of exposure to the marine environment - the contact angle of the water droplet was the greatest of all those observed on the other paints.
- No major mechanical damages were observed.

Hempel S-2103

- No ice-phobic properties were observed at temperatures close to freezing or below.
- Mechanical removal of the accreted ice as difficult as from the test plate coated with general marine paint.
- Poor hydrophobic properties caused the water droplets to spread into a thin film on the surface.
- No major mechanical damages were observed.

TABLE 3.2
OBSERVATIONS OF PLATES AND CYLINDERS

DATE	SHIP	ICE THICKNESS (mm) Min.	Max.	EASE OF REMOVAL Easiest to Hardest
26/02/88	CAPE ROGER	2.8	3.5	E,C,A,D,B,F,G (from cylinders)
04/03/88	ASL SANDERLING	0.8	1.7	E,F,B,A,C,D,G
14/03/88	CAPE ROGER	2.0	5.2	E,A,F,B,C,D,G, (from cylinders) (A,C,G,)(B,E,F,)D (plates)
12/01/89	CAPE ROGER	8.0	10.0	B,(A,C,D,E,G),F
14/01/89	CAPE ROGER	3.0	5.0	(A,B,C,D,E,G),F
21/01/89	CAPE ROGER	0.0	3.0	(A,C,E),(B,D,G,F)
22/01/89	CAPE ROGER	0.0	10.0	(A,C,E),(B,D,G,F)
28/01/89	CAPE ROGER	0.0	3.0	(A,C,E),(B,D,G,F)
17/02/89	CAPE ROGER	5.0	7.0	(D,G),(A,C),(B,E),F
28/02/89	CAPE ROGER	0.0	3.0	(A,E)(C,D,G),B,F

TABLE 3.3
WEIGHTS OF ACCRETED ICE ON THE CYLINDERS

DATE	CYLINDER AND CORRESPONDING PLATE							
	K A	L B	M C	N D	P D	Q E	R F	S G
	Weight of Accreted Ice (g)							
26/02/88	120	40	40	30	70	30	40	70
14/03/88	64	54	54	54	70	59	56	54
12/01/89	All cylinders covered equally with 6-8 mm thick ice.							

FIGURE 3.4

PHOTOGRAPHS OF ICE PHOBIC PAINTED PANELS

Example #1

Example #2

Interslick

- The same observations were made as for the Baysilone, except for the following:

  . Good hydrophobic properties were retained, however, the contact angle of the water droplets seemed to be slightly smaller than that observed in the Baysilone.

  . Some minor mechanical damages was observed, caused by personnel rather than by the environment - adhesion of the coating to the substrate was good.

Interlac - the reference paint

- The same observations were made as for the Hempel S-2103.

Defro S-111

- The same observations were made as for the Baysilone, except that it had good hydrophobic properties, similar to the Interslick.

Hempel S-2104

- The same observations were made as for the Hempel S-2103 except for the following:

  . Some rusty spots developed on the paint surface.

  . Some visible scratches resulted from testing the strength of the coating, not from environmental effects.

Inerta 160

- The same observation were made as for Hempel S-2103 or for the reference paint, except for the following:

  . Hydrophobic properties were slightly better than for the other non-silicone type paints.

  . There were no signs of mechanical wear or damage.

Although there were few icing events over the two year period, and none of these were serious, there was sufficient to allow some comparisons to be made. These observations are discussed in Section 4.

3.3.2 Heat Tracing

a) Arrangement of the Experiment

This experiment was arranged on the 'CAPE ROGER', as shown on Figure 3.1. Three panels were fitted with a means of heating - two were new and one was already on board (the 'Canada' sign). The Raychem 20QTV1 heater was selected with a thermal output as shown on Figure 3.5. For ambient temperatures around 0°C the output is 23 W per linear foot.

For the central plate, to provide more flexibility, the port side had heating tape at a 55 mm spacing and the starboard side at 75 mm, corresponding approximately to 1,000 W/m^2 and 800 W/m^2 respectively. The heating tape was provided with a suitable power connection kit and with an end seal kit. The tape was fixed to the plate by means of an aluminum adhesive tape. The back side of the plate, with the installed heater, was insulated with one inch thick Armaflex II elastomeric PVC/Nitrile closed cell thermal insulating foam. The insulation was waterproof and recommended for a temperature range from -40°C to +105°C.

For the other two test plates, due to steel being a poor conductor of heat, it was thought to be more appropriate to install the heaters on aluminum plates. Since the available mat heaters had dimensions of 1,000 x 100 mm and were rated at 640 W, three were ordered. Two were installed on the back of the starboard plate (1,300 x 980 mm), and one on the back of the port plate (1,300 x 615 mm). That configuration was expected to provide power densities of 800 W/m^2 on the port plate and 1,000 W/m^2 on the other. The back of both plates was insulated with one inch thick Armaflex II PVC/Nitrile closed cell foam. The heaters were of the four-ply, waterproof version with a one metre, two core connecting cable and mounted in a horizontal position using Silicoset 152 RTV adhesive.

All heaters were connected to a power supply, fused and with an on/off switch with indicator lamp (located in the wheelhouse). A Dranetz Series 808 electric power/demand analyzer was also installed in the wheelhouse to automatically take measurements at required intervals and record them on paper tape.

The position of these panels allowed photographs to be taken from the bridge wings or wheelhouse windows or from the main deck.

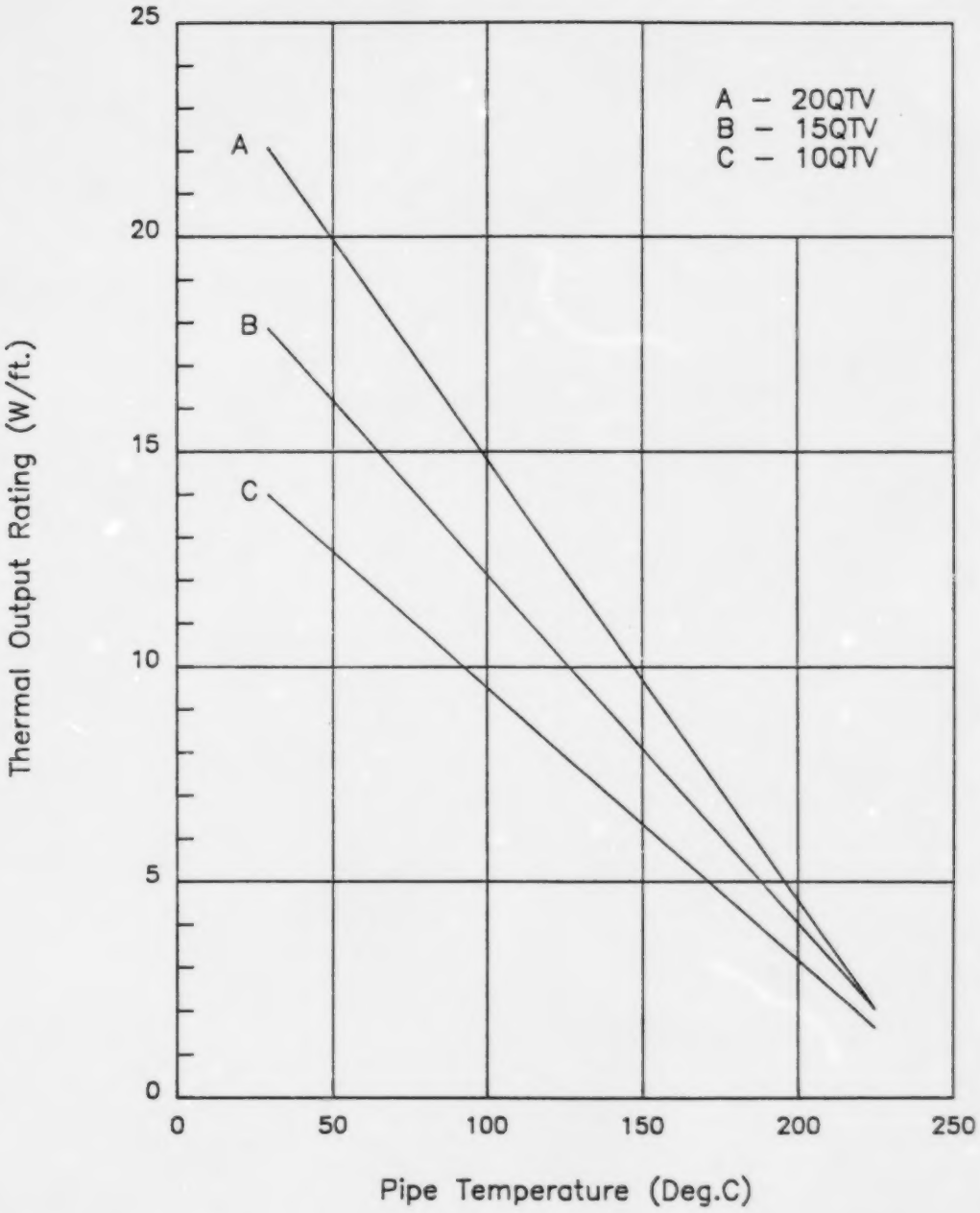
The panels were installed during January 1988 and were exposed to the environment until their removal in March 1989, although the port and starboard panels were removed in December 1988 to make way for the inflatable panels. Therefore, these heated panels were monitored only during the 1988 icing season (January to March).

b) Results

The data which was collected takes the form of observations, measurements and photographs. The observations and measurements are tabulated in Table 3.4 and an example of the power demand is shown in Figure 3.6. A selection of photographs taken during icing incidents are attached as Appendix 6 and two examples are shown in Figure 3.7.

FIGURE 3.5

THERMAL OUTPUT OF RAYCHEM HEATERS



Power output on an insulated metal pipe.

TABLE 3.4

HEATING PANEL OPERATING DATA

DATE	TIMES OF OPERATION On	Off	AIR TEMPERATURE	% OF ICE REMOVED Stbd	Center	Port
26/02/88	1300	1500	-5°C	95	98	95
14/03/88	0905	0940	0.0°C	95	95	95
16/03/88	0825	0850	0.5°C	90	98	95
12/01/89	0950	1425	-7°C	-	50	-
14/01/89	1415	1610	-5°C	-	95	-
21/01/89	0910	0950	-1°C	-	98	-
22/01/89	continuous		4.5°C	-	100	-
28/01/89	0910	0950	-12°C	-	95	-
17/02/89	0846	0919	-7°C	-	95	-
28/02/89	0652	0717	-1°C	-	95	-

Sample Output From the Power Demand Analyzer
(taken at one minute intervals)

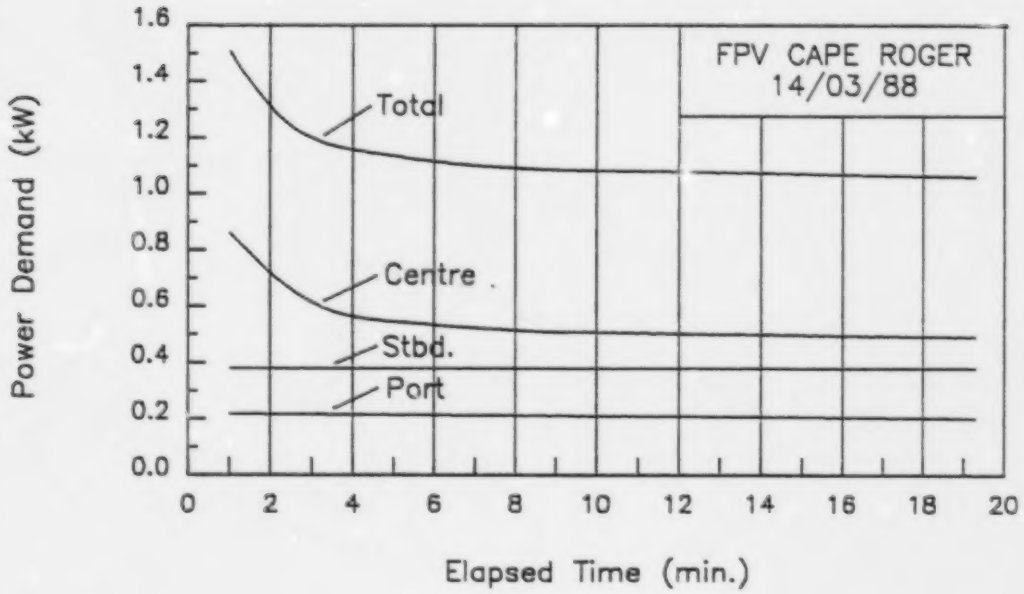
```
---1.037KW .99PF
14-Mar-88 09:35:41

Rt 1.037KW .99PF
14-Mar-88 09:35:41

Status
14-Mar-88 09:35:45

A  120.0 V
B  120.0 V
C  120.0 V

A  1.664 A
B  3.155 A
C  3.831 A

A  199.6 W
B  378.6 W
C  459.7 W
T  1 038 KW
```

Legend:

A = Port Panel
B = Stbd. Panel
C = Central Panel
T = Total
PF = power factor

FIGURE 3.6

POWER DEMAND OF THE HEATERS



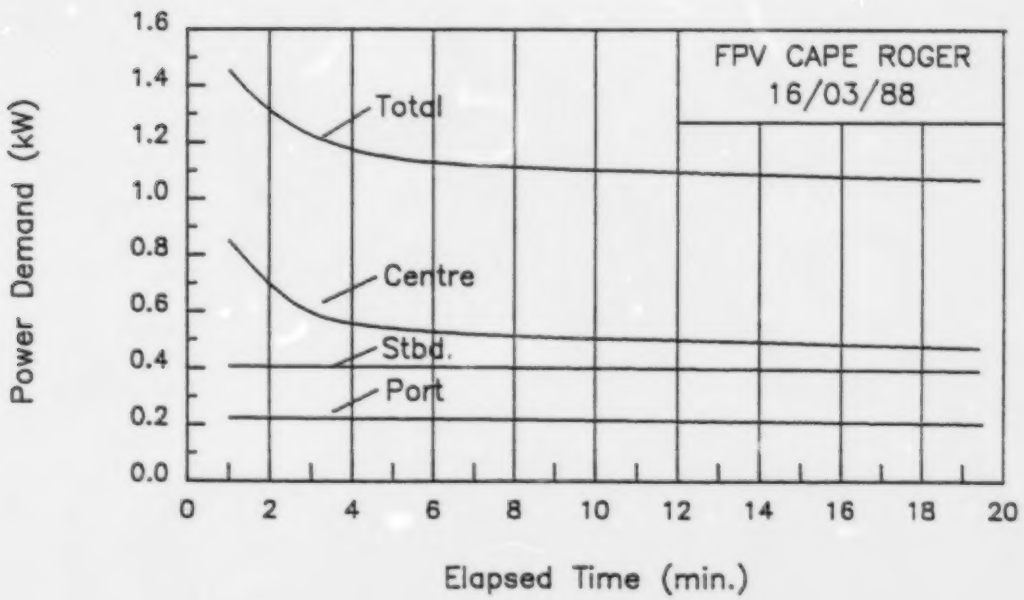
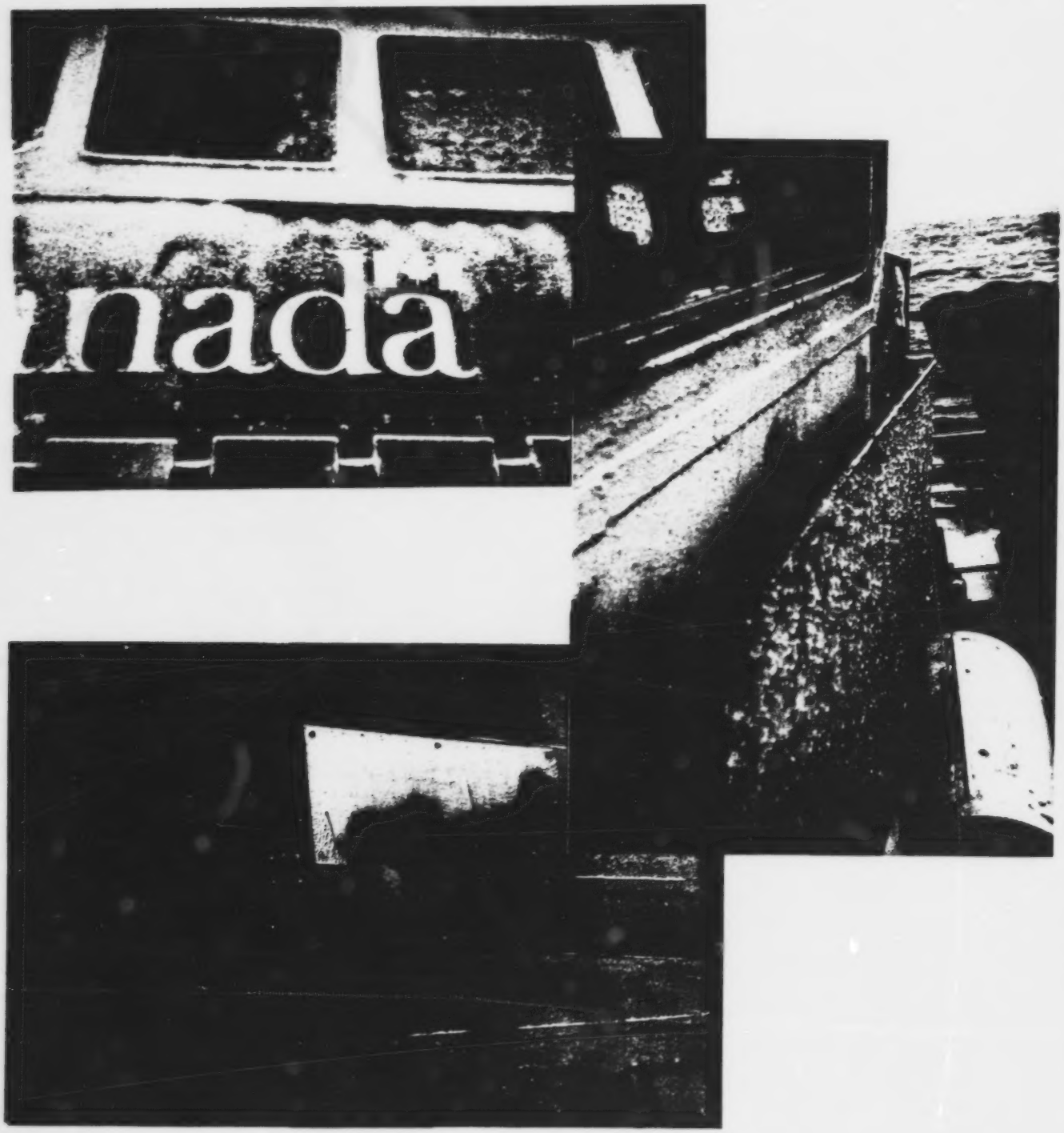


FIGURE 3.7

PHOTOGRAPHS OF HEATING PANELS



Although the icing was insufficient to be conclusive, some observations can be made on the performance which was observed from each heated panel.

- The heating panels were very effective for removing thin layers of ice at temperatures around freezing. The maximum recorded power densities for those conditions were:

  250 w/m^2 - aluminum port panel
  314 w/m^2 - aluminum starboard panel
  419 w/m^2 - steel panel with the Raychem heater

  All panels covered with 4 to 7 mm thick ice were usually de-iced in 15 to 30 minutes.

- Ice was melted in a more uniform way on the central panel, which was equipped with heating tape, than on the panels with mat heaters, even those made of aluminum.

- When the central panel was exposed to 30 knot winds at -1°C and iced-up to about 2 to 3 mm in thickness, its power density increased rapidly to 1220 W/m^2 and the de-icing period lasted about 40 minutes.

- At a temperature of around -10°C the central heated panel was found to be effective as an anti-icer. When turned on, ice did not form on its surface.

- De-icing at temperatures of about -10°C was not so effective and depended greatly on the wind strength. When the wind was strong, there was no progress made in de-icing, but when sheltered the ice started melting immediately.

- When covered with heavy ice (more than 20 mm) the central panel did not work well as a de-icer because the ice shell tended to form an ice bridge over the heater after melting a thin layer next to the plate. That, in turn, resulted in warming up the heater and thus decreasing its output.

- Methods of attaching insulating foam to the panels, and the panels themselves to the superstructure, as well as the arrangement of electrical connections were found to be adequate - no defects were found.

Although there were few icing events over the two year period, and none of these were serious, there was sufficient to explore the efficiency of these heated panels. The results seem to indicate some clear conclusions and these are discussed in Section 4.

3.3.3 Air Guns

A pneumatically operated air hammer, fitted with a chisel bit, was taken on board the 'CAPE ROGER', to be operated from the ship's service air system at 700 kPa.

There was no occasion to test the air hammer, but it's use was discussed with the engineering staff onboard. There was concern that the hammer might damage the paint work and deck equipment, but a specific application was identified. In heavy freezing spray the freeing ports in the deck bulkwarks will freeze over such that water shipped on deck cannot drain away.

In enclosed areas, such as under the helicopter deck on the 'CAPE ROGER' a significant free surface may result with the deck becoming a dangerous work area. Presently, the only method for unblocking the freeing ports is with the use of small wooden mallets. A pneumatic air hammer would be useful in such situations. Construction of a hammer bit of softer material than tool steel might reduce the concern about damage to the ship.

3.3.4 Inflatable Panels

a) Arrangement of the Experiment

This experiment was arranged on the 'CAPE ROGER' during the winter of 1988/89, as shown on Figure 3.8. Two panels were fitted, one on each side directly below the bridge wings.

Several companies were contacted about materials which might be suitable for the inflatable panels. Among those companies were:

- Dunlop-Beaufort Canada Ltd., Richmond, BC
- TUL Safety Equipment Ltd., Hawkesbury, ON
- 3M Energy Control Products, Monrovia, California, USA
- Uniroyal Coated Fabrics, Indiana, USA
- Herculite Products Inc., New York, USA
- Pawling Corporation, Pawling, New York, USA
- Presray Corporation, Pawling, New York, USA
- Du Pont Canada Inc., Mississauga, ON
- CHR Industries Inc., New Haven, Connecticut, USA
- Perma-Flex Inc., Montreal, PQ
- Stedfast Inc., Granby, PQ

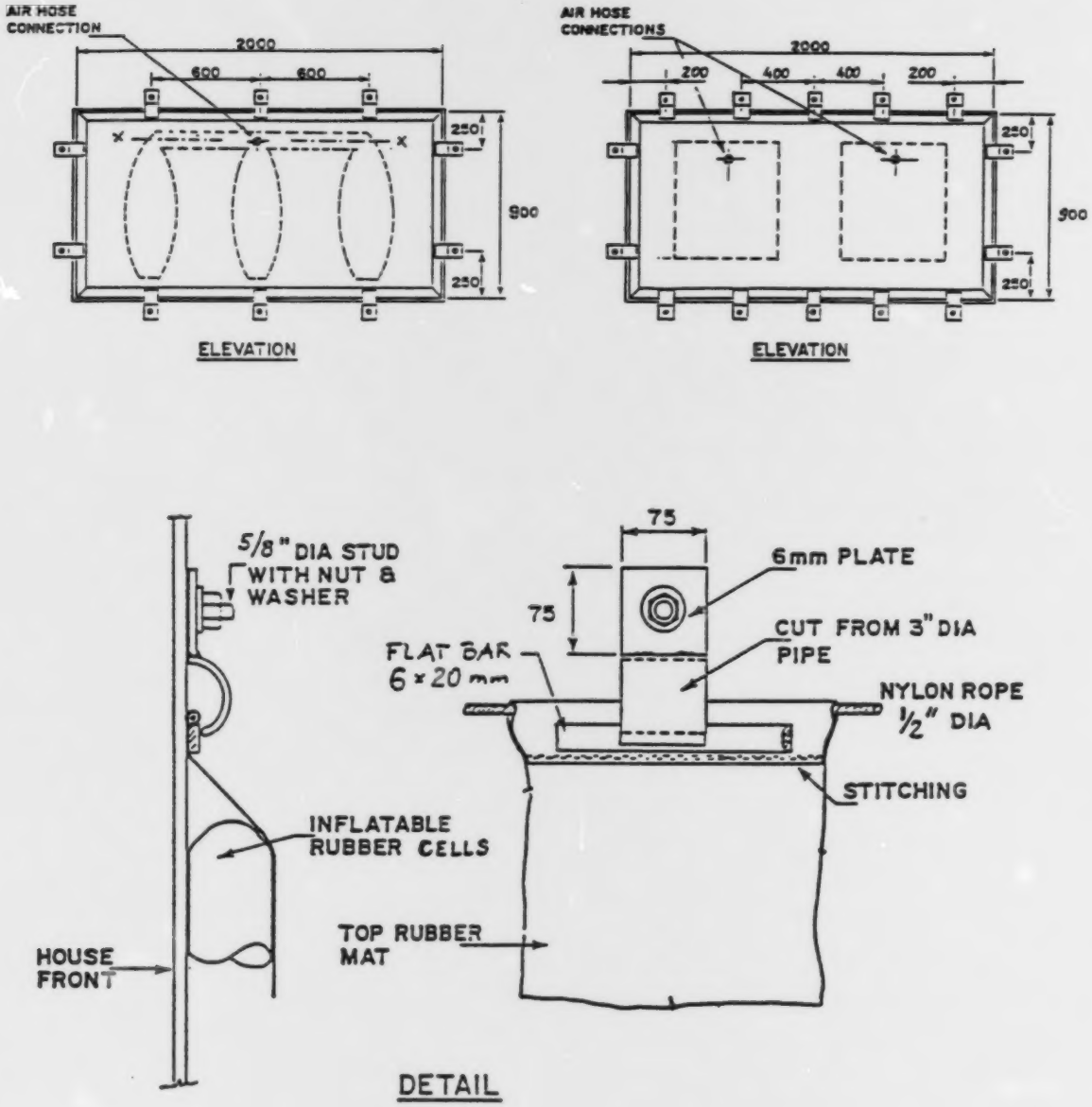
As shown on Figure 3.8, the panels measured 2,000 mm x 900 mm and were designed to fit the available space. Each panel consists of an outer cover and internal air chambers. While one of the panels has two square chambers, the other has three chambers of an elliptical shape. All air chambers are outfitted with flanges and air inlet connections. The most feasible materials appeared to be those used for the construction of inflatable liferafts i.e., Neoprene or Butyl coated nylon fabrics. The panel fixing arrangement includes nylon ropes sewn into the perimeter of the panels, steel retaining bars and a set of clamps bolted to the superstructure.

Two Canadian companies were selected to manufacture the inflatable panels:

- TUL Safety Equipment Ltd.
- Dunlop-Beaufort Canada Ltd.

FIGURE 3.8

INFLATABLE DE-ICING PANELS



Both are experience in manufacturing inflatable liferafts and they have extensive knowledge of the use of rubberized fabrics in marine and Arctic environments.

TUL Safety Equipment produced the panel with two square internal air bags using nylon fabric coated with neoprene. When shop tested, the panel was found to be air-tight and to have a desirable curvature on its outer surface. The other panel was produced by Dunlop-Beaufort Canada Ltd. They applied their own technique, using the butyl coated nylon fabric from which they manufacture inflatable liferafts.

COLDA Mechanical Ltd. installed the panels. They prepared all fittings, valves and miscellaneous equipment necessary to fix and hook up the inflatable panels. Cable penetrations in the bulkhead were used for running out compressed air tubes.

A control panel consisting of two reduction valves, two shut off valves, two deflation valves and two manometers was installed on the bridge. It was connected through a filter and shut off valve to the compressed air line serving the ship's system.

The inflatable panels were installed during December 1988 and were exposed to the environment until their removal in March 1989. Therefore, these inflatable panels were monitored only during the 1988 icing season (January to March).

b) Results

The data which was collected takes the form of observations, measurements and photographs. A selection of photographs taken during icing incidents are attached as Appendix 7 and two examples are shown in Figure 3.9.

Although the icing was insufficient to be conclusive, some observations can be made on the performance which was observed from each inflatable panel.

- The port side panel effectively removed 7 to 8 mm of ice from its surface by inflating it to an air pressure of about 70 kPa.

- The removal of thinner ice layers was not effective.

- Both panels developed adequate curvature in 20 to 30 seconds at an air pressure of about 50 kPa.

- The neoprene coated fabric of the starboard panel was less prone to ice adhesion than the butyl coated fabric on the port side panel.

- Deflation of the panels induced by wind pressure on the superstructure was generally not sufficient and deflation had to be assisted.

FIGURE 3.9

PHOTOGRAPHS OF INFLATABLE PANELS

- Generally, more ice was accreted around compressed the air tube connectors. That ice was usually not removed through the inflation procedure.

- The rigid compressed air tubes and their connectors restricted to some extent the flexibility of the panel and its ability to deflate under the wind pressure.

- The inflation control equipment located on the bridge was found adequate to operate the panels, even on the occasions when frequent de-icing was required.

- The mode of ice shedding from the panel being inflated was found to be exactly as predicted. The ice cover broke into small pieces, which eventually peeled off the panel surface.

Since there were few icing events over the two year period, and none of these were serious, there is insufficient data to explore the efficiency/ usefulness of these inflatable panels. The results seem to be positive but lack of data will prevent firm conclusions being reaching. The results are discussed in Section 4.

4. DISCUSSION

The objective of this section is to review the observations or data which was collected from each experiment with a view to elaborating on the potential of each de-icing or anti-icing system. Where conclusions can be reached they will be discussed. Where conclusions cannot be reached, recommendations will be made for a further course of action.

4.1 Ice Phobic Paints

From the results of the laboratory and shipboard experiments it is clear that some benefits can be obtained from several of the paints/coatings. Although insufficient data was available, there were performance characteristics observed which would likely be present and as useful during severe icing as during the more mild occurrences. The following notes discuss each of the coatings.

a) Baysilone

At temperatures around freezing, the paint usually prevented ice or snow accumulation. This could be recognized by its almost clear surface, while some of the other test plates were covered with sleet. At lower temperatures, generally, there was no difference between plates in the amount of accreted ice. However, the pattern of initial icing was distinct from that observed on the non-silicone type paints. The Baysilone most often appeared to be covered with ice beads rather than a layer of ice. That difference decreased as the ice layer grew thicker.

Mechanical removal of the accreted ice was considerably easier than from the non-silicone paint surfaces. When the ice shell was hit with a mallet, broken ice pieces more readily fell than with non-silicone type paints. However, this observation was made at temperatures down to about -10°C and care must be taken to extrapolate it to lower temperatures.

The Baysilone wear and weathering resistance appeared to be the best of all of the paints tested. This conclusion has been drawn from a wetability test after one year onboard the 'CAPE ROGER'. All of the test plates were splashed with water at an ambient air temperature of about 3°C and macro-photographs were taken of the water droplets remaining on the surface. From the appearance of the droplets, or rather from their contact angle (the angle between the surface of the plate and the line tangent to the droplet surface at the contact point with the plate, which is a generally accepted measure of hydrophobic properties of the material) the ability to repell water, and indirectly ice, can be assessed. The water droplets on the Baysilone plates are characterized with a large contact angle. That means, that despite a year of weathering in a marine environment, most of the hydrophobic properties of the paint were preserved.

b) Hempel S-2103

Although well preserved during a one year period, this paint did not show any signs of ice phobic or hydrophobic characteristics. Ice and snow

was adhering as strongly as to the other parts of the superstructure. Spraying with water for the wetability test created a uniform film of water without forming single water droplets on the surface.

c) Interslick

The Interslick coating performed surprisingly well. Because of its soft nature it was not expected to last long. However, after a year the test coat remained intact and the hydrophobic and icephobic properties were still present. Its interaction with ice and water was very similar to that observed on the Baysilone plate. The wetness test developed single water droplets adhering to the paint surface with contact angles slightly lower than for Baysilone.

d) Interlac

As a reference paint it was usually iced up to the same degree as adjacent areas of the superstructure.

e) Defros S-III

The third silicone type paint performed the same as Baysilone and Interslick. The shape of the water droplets in the wetability test was assessed (without sophisticated measuring techniques) as equal to the shapes seen on the Interslick surface.

f) Hempel S-2104

This graphite-like coating did not fulfill the manufacturer's expectations. As with other non-silicone coatings there was no noticeable difference in the amount and adhesion strength of the ice accreted to this paint and to others of this type. The wetability test was also completed. Its soft and probably porous structure was the likely reason for sea water penetration down to the substrate, causing rusty spots on its surface.

g) Inerta 160

It was not possible to identify any superior anti-icing properties of this coating in comparison to the other non-silicone paints. However, some difference in wetability could be seen. The film of water was not entirely uniform but broken in some places like on a greasy surface. The most noticeable feature of this paint was the glossy appearance of its surface, completely without any marks of weathering or even small signs of mechanical damages.

h) Summary

The silicone based paints/coatings (Basilone, Interslick and Defro S-III) exhibited characteristics which are desirable in an ice phobic paint. The icing started as beading rather than as a sheet and was much easier to remove. In addition, the wearability of these coatings seemed to extend at least for the two year period of the experiment. Unfortunately, the experiments were of insufficient duration and experienced insufficient icing to allow firm conclusions to be drawn.

4.2 Heating Panels

From the results of the shipboard experiments, it is clear that benefits can be obtained from some form of heating. Although insufficient data was available, there were performance characteristics observed which would likely be present and as useful during severe icing as during the more mild occurrences.

Self-regulating heaters are suitable for anti-icing. However, their power consumption may be unnecessarily high, since the temperature of the panel surface is not controlled and may at times be higher than 0°C. This type of heater is not useful for de-icing as their output decreases due to the insulating action of the ice cover. The difference between de-icer power demands for extreme conditions is large, extending from about 200 w/m^2 to at least 1300 w/m^2.

Trace heating tape attached properly to the heated panel appears to provide a better distribution of heat than mat heaters of the same capacity. The best arrangement seems to be an ordinary trace heating tape attached to the panel with a density of about 1300 w/m^2. The output of the panels could be controlled by a thermostat maintaining the surface temperature slightly above 0° during anti-icing operation. For de-icing purposes, the full capacity of 1300 w/m^2 may be required.

4.3 Air Hammer

There was insufficient icing during either of the two years to allow an air hammer to be tested. Some discussions were held with the crew onboard the 'Cape Roger' to obtain their views. They thought that an air hammer could be used to break ice away from the freeing ports, thus allowing trapped water to escape. However, they did not think it an appropriate means of de-icing sensitive items of equipment.

4.4 Inflatable Panels

From the results of the shipboard experiments, it is clear that benefits can be obtained from some form of inflatable panel. Although insufficient data was available, there were performance characteristics observed which would likely be present and as useful during severe icing as during the more mild occurrences.

Less icing on the neoprene panel than on the butyl panel may be explained by the different properties of both materials and by the greater flexibility of the neoprene panel top surface. It was slightly thinner than the butyl fabric and was not supported by compressed air tube connections in the center of the panel. As a result, it behaved similarly to the tarpaulin covering on rescue boats. In most instances, through constant movement, ice was prevented from forming.

The size of a single inflatable panel should not be greater than was used in these experiments, as a larger panel would required unreasonably heavy fittings and fabrics.

Limited time did not allow an estimate to be made of the wearability and resistance to weathering of the coated fabrics. To permit such an assessment to be made, an inflatable panel should be left on board for a period of at least four years.

The performance of the panels in heavy icing has not been assessed. However, it may be assumed with confidence, that the heavier the ice layer, the better the de-icing effectiveness. Heavier icing may require only a slightly higher inflation pressure. However, an inflation time of 30 seconds may be too long for circumstances when inflation is carried out during an icing storm when slowly breaking ice pieces may be stuck together with incoming freezing water droplets. The inflation time can be shorter if 3/8 inch diameter tubes are used instead of 1/4 inch. A safety valve is indispensable in the air inflation system and, the deflation performance could be improved by connecting the panel tubes to a vacuum source.

Attachment of the panel to the ship superstructure by means of a retaining rope (sewn into the perimeter of the panel) and a steel flat bar was acceptable for the experiments. However, the flat bar should be secured by bolts projecting through the flat bar and the rubberized fabric, properly reinforced around any holes.

The size and number of the panel retaining flat bars should be limited as far as possible. This may be achieved by overlapping edges of the adjacent panels in order to use a single row of studs and a single flat bar for securing both of the panels.

The number of compressed air tube connectors should be kept to the minimum, thus reducing the amount of icing around them. The compressed air tubes should be made of rubber hoses in order not to restrict flexibility of the panels.

The colour of the panels should be similar to that of the surrounding ship structure, as the black one will not be favoured by any ship owner and because it practically does not offer any advantages in anti-icing. On the contrary, the black colour may increase the weathering rate of the material in summer months.

It was clearly demonstrated that this method is the most effective and the least energy consuming. When a larger area is to be covered with inflatable de-icers, their capital and installation cost will be considerably lower per unit area than for the simple panel used in these experiments. This is not the case for heat tracing, or ice phobic paints, which costs are directly proportional to the covered surface area.

5. CONCLUSIONS

The overall objective of this project was to be able to draw firm conclusions on the usefulness of several anti-icing and de-icing systems. The lack of severe icing events during the two year period of the test program greatly reduced the opportunities to witness the efficiency of the various optional systems. Although the overall objective was not achieved, much has been learned. The conclusions which can be drawn from these experiences, and recommendations which seem to be appropriate are presented in the following notes.

5.1 Conclusions

The conclusions presented below are based on the observations made and the analysis conducted. No attempt has been made to embellish the results or to extrapolate from these results to a systems expected performance in more severe icing incidents.

a) Ice Phobic Paints/Coatings

Experiments with ice phobic coatings were conducted in the laboratory and onboard two ships. Both sets of experiments were planned, organized and carried out successfully and some conclusions can be drawn:

i) The ice adhesion tests conducted in the laboratory showed a distinct difference in the adhesion strength of ice to the various coatings. In order of least adhesion strength the coatings can be ranked as:

- Interslick
- Defro S-III
- Baysilone
- Interlac
- Hempel S-2104
- Hempel S-2103
- Inerta 160

The shipboard experiments indicated approximately the same order of performance ie., the three silicone based coating were superior to the others in terms of ice removal.

ii) The abrasion resistance tests conducted in the laboratory also showed a difference in the performance of the various coatings. In order of most abrasion resistance the coatings can be ranked as:

- Interlac
- Inerta 160
- Interslick
- Baysilone
- Hempel S-2103
- Defro S-III
- Hempel S-2104

The shipboard experiments were inconclusive, since there was no appreciable abrasion on any of the coatings.

iii) The impact tests conducted in the laboratory were quite rudimentary, but they did illustrate the superiority of Inerta 160 (which sustained virtually no damage). Of the ice phobic paints, Baysilone suffered the least damage. The shipboard experiments gave no indication of impact resistance in service.

iv) During the shipboard experiments, the Hempel S-2104 coating was marred by a number of rust spots indicating either improper application of the coating or a more fundamental breakdown of the coating system.

It appears that the three silicone based coatings exhibited good ice phobic properties in combination with acceptable ice adhesion, abrasion and impact properties, except for Defro S-111 (which had a low abrasion resistance).

b) Heating Panels

Experiments with heating panels were conducted onboard one ship. The experiments were planned, organized and carried out successfully and some conclusions can be drawn.

i) Self-regulating heaters are suitable for anti-icing but not for de-icing (since the heat output decreases due to the insulating action of the ice cover).

ii) The de-icer power demand for extreme conditions can range from 200 to 1300 W/m^2.

iii) The best arrangement seems to be an ordinary heat tracing tape attached to the panel with a density of 1300 W/m^2, with the output being controlled by a thermostat during anti-icing, and using the full output during de-icing.

Heated panels are a practical means of anti-icing and de-icing, particularly for the protection of sensitive equipment or machinery which is not sufficiently robust to withstand the use of heavy mallets.

c) Air Hammer

No conclusions can be drawn from these experiments since there was insufficient icing to allow the air hammer to be used.

d) Inflatable Panels

Experiments with inflatable panels were conducted onboard one ship. The experiments were planned, organized and carried out successfully and some conclusions can be drawn.

i) Both types of inflatable panel (butyl and neoprene) were effective, but the one made from neoprene material was most effective. That material was thinner and more flexible and therefore was less prone to accumulate ice.

ii) The attachment of the panels to the superstructure surface needs to be carefully considered.

iii) The size of the panels should be kept to about the size of those tested 1 m^2, otherwise the retaining fittings will have to be much larger and more cumbersome.

iv) The colour of the panels should/can be the same as the superstructure since no beneficial effect is thought to be obtained from using a dark colored material.

Of all the methods tested these inflatable panels seem to be most effective for de-icing, and will be the least energy consuming. These panels are a positive way of removing ice from a protected surface and they can be used selectively, for equipment or sensitive areas, or even for large areas.

e) Summary

In summary, although these experiments were marred by a lack of serious icing incidents, much was learned about the effectiveness of several proposed methods of anti-icing and de-icing. Effective use can be made of ice phobic coatings, heat tracing and inflatable neoprene panels. The selective use of these methods would seem to be the most appropriate approach.

Where stability is a concern, the higher locations on a ship such as masts and upper superstructure can be protected by ice phobic paint and inflatable panels. Sensitive equipment in these areas can be heat traced. This strategy will also keep these methods, which can be prone to physical damage, away from heavy traffic zones. In lower parts of the ship, where safety of operation for personnel is of most concern and traffic may be higher, heat tracing and protective covers may be more applicable.

The precise use of these methods in various parts of the ship will depend on the type of vessel and the rationale for anti-icing and/or de-icing ie., protection of ship stability, personnel safety/access or equipment protection.

5.2 Recommendations

The overall recommendation which flows from this work is that research should continue on the general topic of the icing of ships. The two years of experience obtained by this project was adversely effected by mild weather and, as a result was inconclusive. Only further testing of specific solutions will fill-out the data base to the necessary extent to allow firm recommendations to be made. Specifically, the following recommendations can be made:

a) A small vessel which operates in the sea lanes between P.E.I. and Newfoundland, during the months of January and February, should be found and encouraged to take part in a further set of experiments.

   This area is the most icing intensive on the Southern East Coast and is most likely to produce a substantial body of data.

b) The equipment used in these experiments should consist of:

   - Three ice phobic painted panels.
   - One inflatable panel made from a neoprene material.
   - The selective use of heat tracing tape.

   These experiments should use the existing equipment and be restricted to data collection and analysis using photography to the greatest extent practicable (considering the hazardous weather conditions).

c) An assessment should be made of the practical uses of the proposed methods onboard a range of ship types. These ships/vessels should include:

   - Fishing Boats
   - Ferries
   - Offshore Supply Vessels and related Oilfield Support Ships (and/or Handlers, Diving Support and Standby Ships)
   - Offshore drilling and production rigs (Semi-Submersibles, Jackups, G.B.S. Structures and Monohulls)

   Since the most practical, and economical use for de-icing or anti-icing measures will be a selective approach, it is quite fundamental to assess where and under what circumstances the various alternatives could be used successfully.

d) A well designed set of laboratory experiments should be completed to duplicate to the greatest extent possible the real conditions of ice accretion. These experiments would collect data on rates of ice accretion, the physics of the accreted ice, the de-icing or anti-icing capabilities of each alternative and the variable performance of each as a function of ice thickness.

Of these recommendations, the latter is probably the most important. Experience with full scale testing has shown how uncertain can be the results. This experience would lead to developing a test methodology which is more likely to be successful. Laboratory experiments have their own problems, such as duplicating the physics of the accreted ice, but at least the parameters of the test can be controlled and a full set of data can be obtained.

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APPENDIX 1

LIST OF CONTACTS

LIST OF CONTACTS

(Highlighted companies have replied)

ICE PHOBIC PAINTS - Producers or Suppliers

1. **International Paints (Canada) Ltd., Montreal**
2. **Devoe Marine Coatings, Dartmouth, NS**
3. Nippon Oil & Fats Co. Ltd., Tokyo
4. Nippon Paint Co. Ltd, Osaka
5. Daniels A/S, Arne B., Osho
6. **Futura Coatings Inc., Hazelwood, USA**
7. Owatrol International Corporation, Oslo
8. Sigma Coatings Ltd., London, UK
9. Leigh & Co. W. & J., Bolton, UK
10. Ameron B.V., Croydon, UK
11. Jotun Marine Coatings, Sandefjord, Norway
12. **Kansai Paint Co. Ltd., Osaka**
13. Astral, St. Denis, France
14. **Hempel International AS, Copenhagen**
15. **Teknos - Maalit OY, Helsinki**
16. Inouye & Co. Ltd., Yokohama
17. **Sikkens BV, Wapenveld, Netherlands**
18. Camrex Ltd., Sunderland, UK
19. Japan Paint Foreign Trade Association, Toyko

ELECTRICAL TRACE HEATING

1. **Nielsen Engineering & Trading Co., Denmark**
2. Minerva B.V., Huizen, Netherlands
3. **Valad Electric Heating Co., Tarrytown, USA**
4. **BICC Pyrotenax Ltd., Hebburn, UK**
5. **Electrothermal Engineering Ltd., Southland-on-Sea, UK**
6. **Isopad Ltd., Borehamwood, UK**
7. L.E.C. Marine Ltd., Lowestoft, UK
8. **Raychem Corporation, Toronto, Canada**
9. **Valcano Co., Ltd., Japan**

INFLATABLE DE-ICING - Potential Producers

1. Dart Air Sea Equipment, Richmond, BC
2. Mil-Com Technologies Inc., Waterloo, ON
3. Presray Sub of Pawling Rubber Corp., Pawling, NY
4. Nordisk (VIKING) Gummibadstabrik AS, Esbjerg, Denmark
5. Toyo Tire & Rubber Co. Ltd., Tokyo
6. Polardykk A/S, Bodo, Norway
7. A.I.M. Safety, Wimborne, UK
8. Dunlop-Beaufort Canada Ltd., Richmond, BC
9. RFD Ltd., Godalming, UK
10. Seaweather Marine & Aviation Services, Dartford, UK
11. Leyland & Bizmingham Rubber Co. Ltd., Leyland, UK
12. Marston - Palmer Plc., Fordhouses, UK

GOVERNMENT AGENCIES

1. Iceland Coast Guard, Reykjavik
2. Japan Maritime Safety Agency, Tokyo
3. Norway Fisheries Directoriate, Bergen
4. Swedish Coast Guard, Stockholm
5. Finish Board of Navigation, Helsinki
6. State of Alaska Dep. of Transportation, USA
7. Fisheries & Oceans, Canada
8. Canadian Coast Guard

SHIPOWNERS

1. Boston Deep Sea Fisheries, Fleetwood, UK
2. Alaska Draggers Association, Kodiak, USA
3. Westward Trawlers Inc., Seatle, USA
4. Fednav Limited, Montreal, Canada

AIR GUNS

1. Babcock & Wilcox, Cambridge, ON
2. Shell International Inc., London, UK
3. Grazebrook Ltd., Dudley, UK
4. Robco, USA
5. Atlas Copco, Montreal, PQ
6. Florida Pneumatic Canada, Kitchener, ON

RESEARCHERS

1. A. Comiskey, Northern Technical Services, Anchorage, USA
2. Ivar Horjen, Norwegian Hydrotechnical Laboratory, Trondheim, Norway
3. O. Houmb, Oceanographic Company of Norway, Trondheim, Norway
4. G. Liljestrom, Gotaverken Arendal AB Goteborg, Sweden
5. S. Loset, Martek, Trondheim, Norway
6. L. Makkonen, Laboratory of Structural Engineering, VTT, Espoo, Finland
7. D. Minsk, Cold Regions Research Engineering Laboratory, Hanover, USA
8. J. Overland, National Oceanic & Atmospheric Administration, Seatle, USA
9. Ship Equipment Division, Ship Research Institute, Tokyo, Japan
10. BSRA, Wallsend, UK
11. VTT Ship Laboratory, Espoo, Finland
12. Hokkaido University, Faculty of Fisheries, Sapporo, Japan

ELECTRICAL POWER COMPANIES (Ice Phobic Paints)

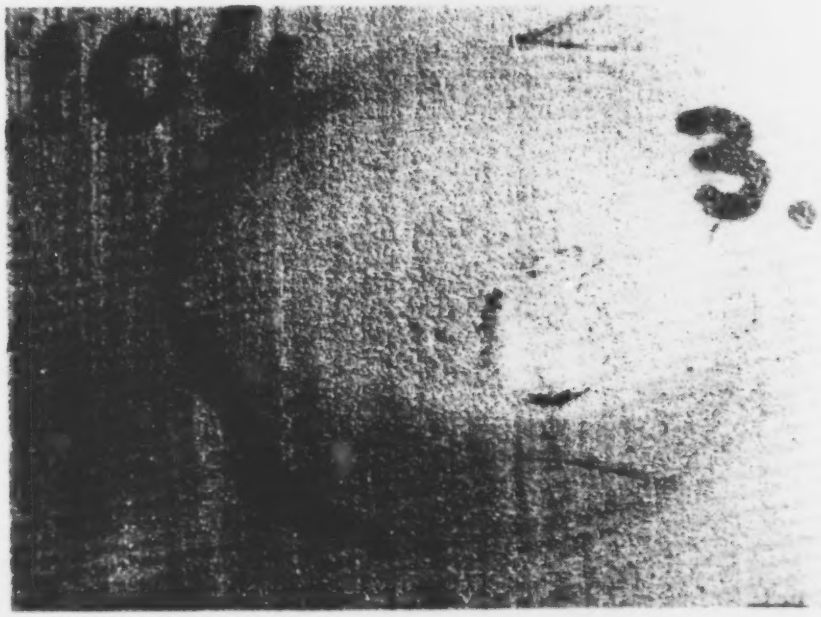
1. CEGB, London, UK
2. NSHEB, Edinburgh, UK
3. Newfoundland & Labrador Hydro, St. John's
4. Nova Scotia Power Corp., Halifax
5. Ontario Hydro, Islington, ON
6. Hydro-Quebec, Varennes, PQ
7. Central Marine Power Co., Augusta, USA
8. Boston Edison Company, Boston, USA
9. Eastern Edison Company, Brockton, USA
10. Japan Trade Centre, Toronto, ON

APPENDIX 2

ABRATION AND IMPACT TEST PHOTOGRAPHS

FIGURE 3.9

ABRASION RESISTANCE TEST

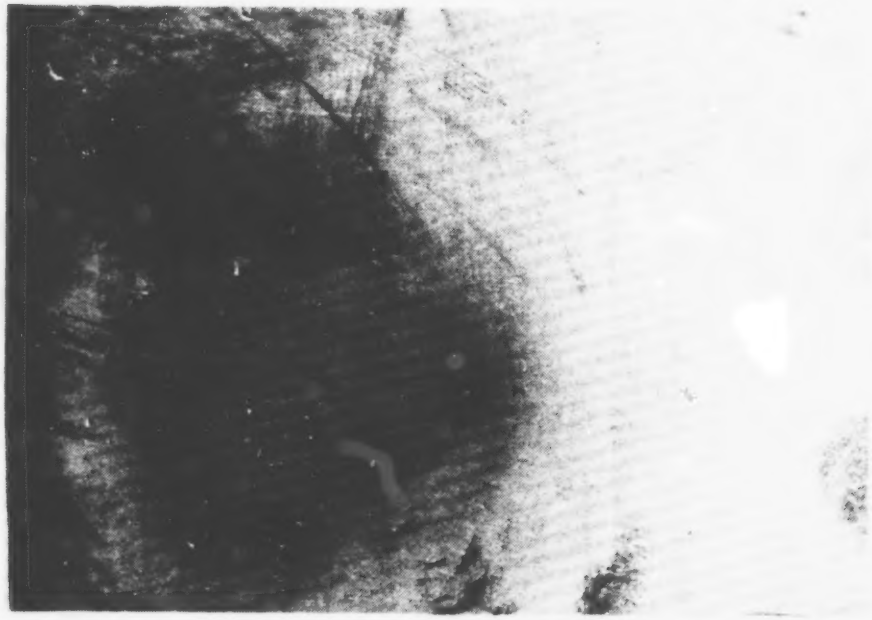


Hempel S-2104

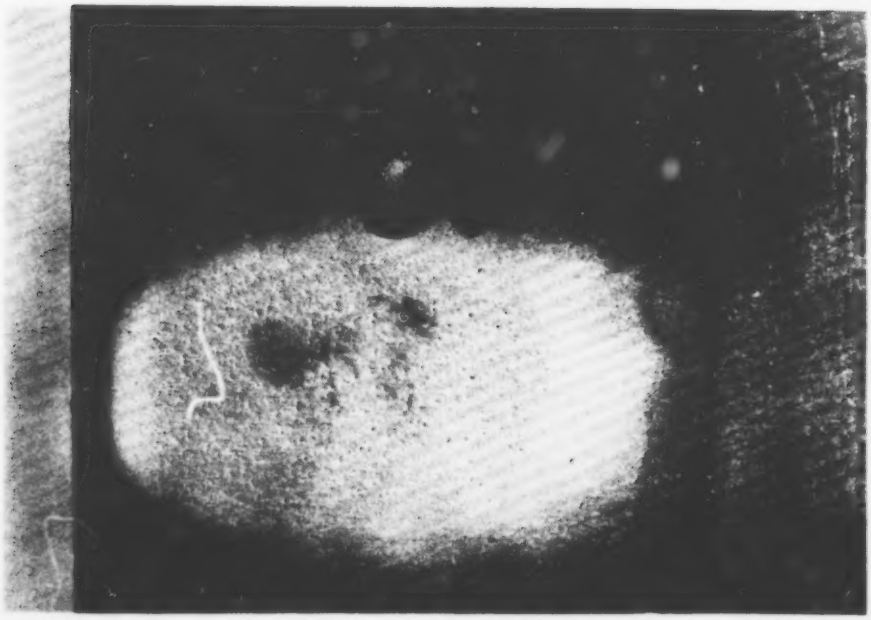
Hempel S-2103

FIGURE 3.10

ABRASION RESISTANCE TEST



Interslick



Inerta 160

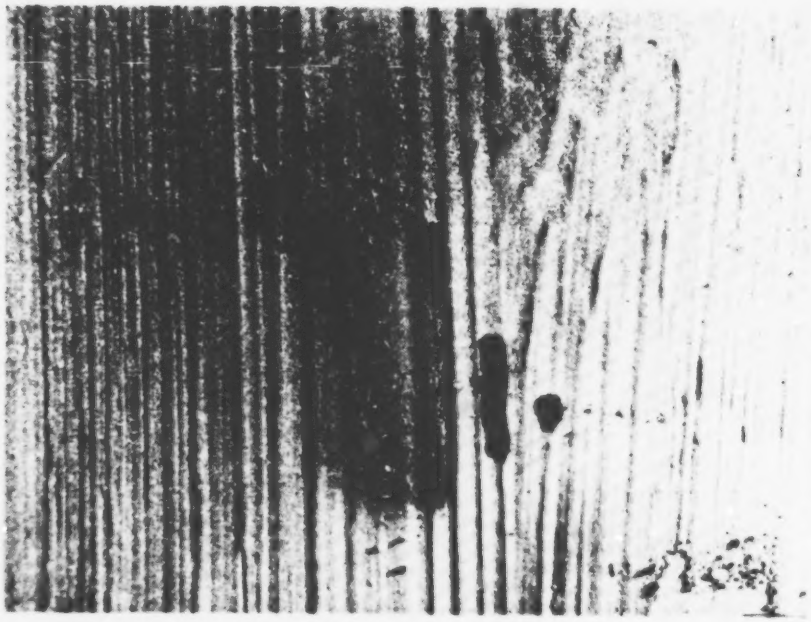
FIGURE 3.11

ABRASION RESISTANCE

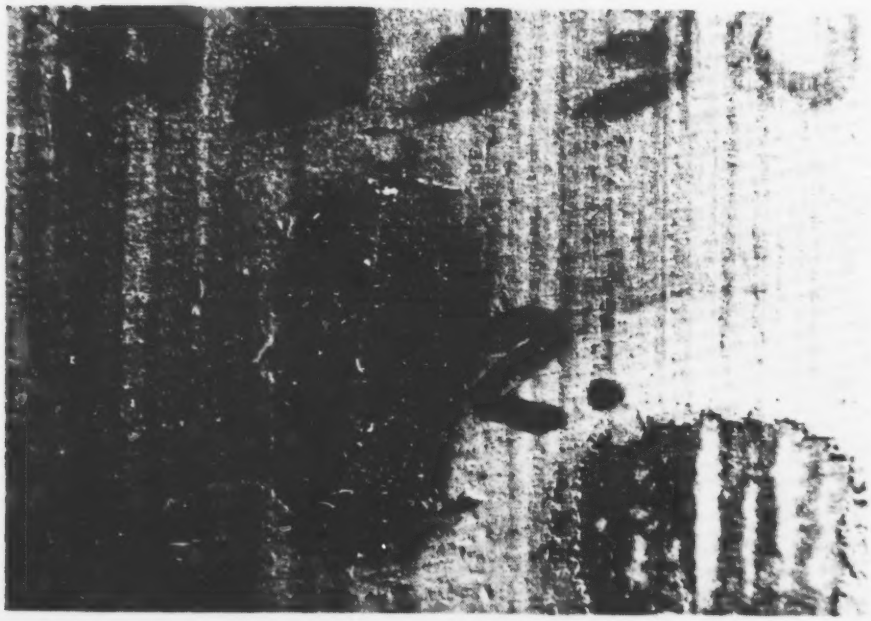
Interlac

FIGURE 3.12

SCRATCH TEST



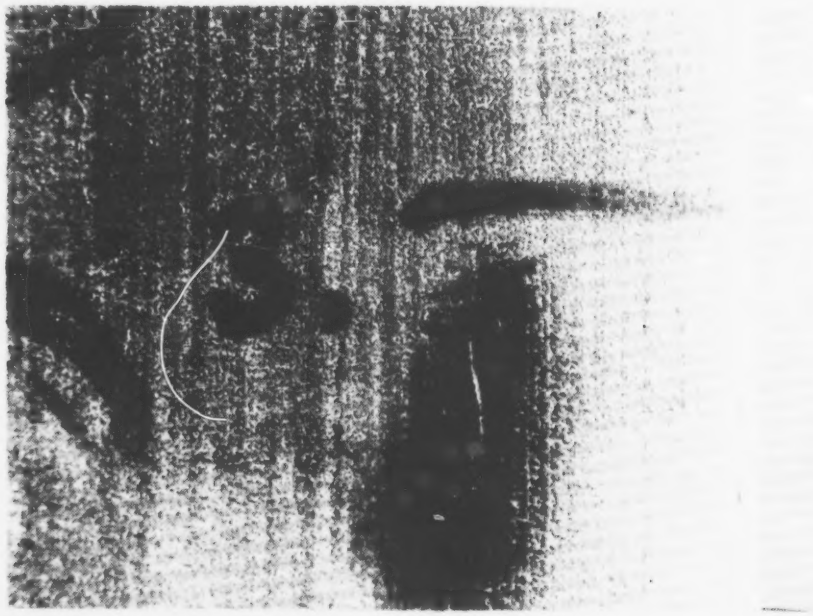
Baysilone



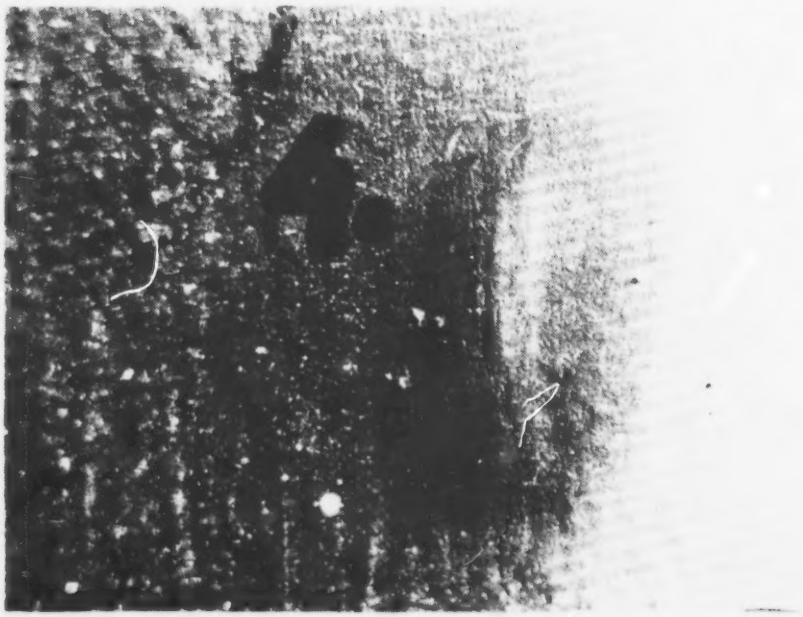
Defro S-III

FIGURE 3.13

SCRATCH TEST



Hempel S-2104



Hempel S-2103

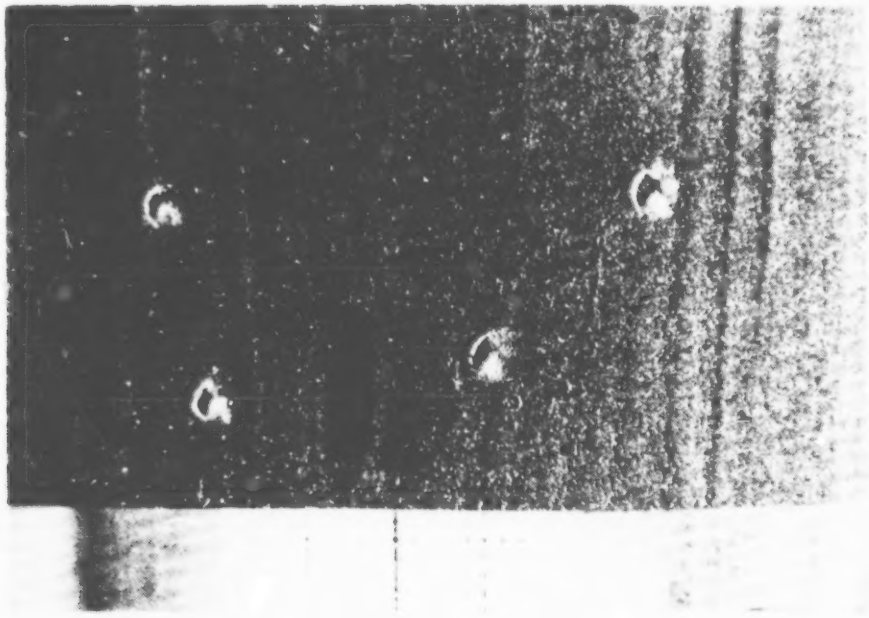
FIGURE 3.14

SCRATCH TEST

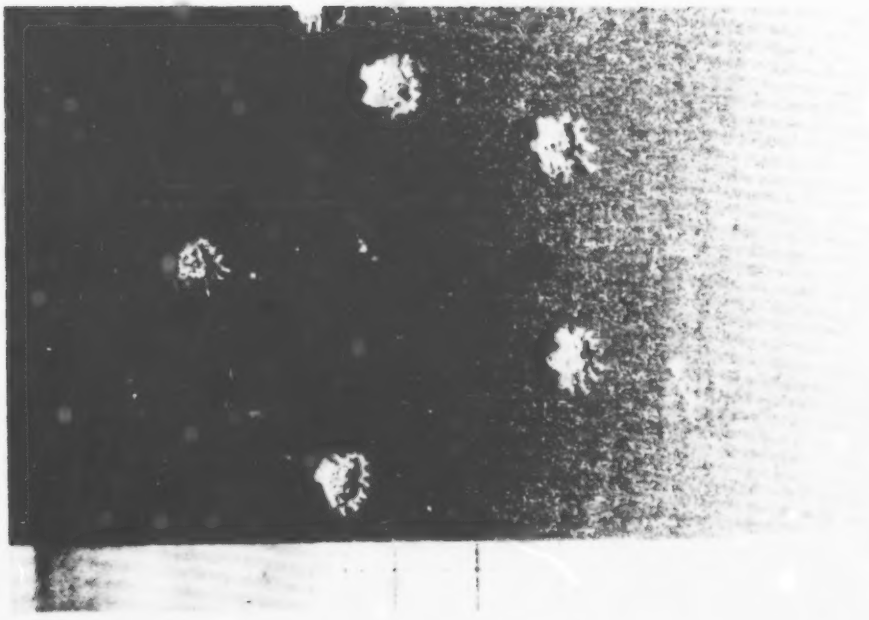
Interslick

FIGURE 3.16

IMPACT TEST



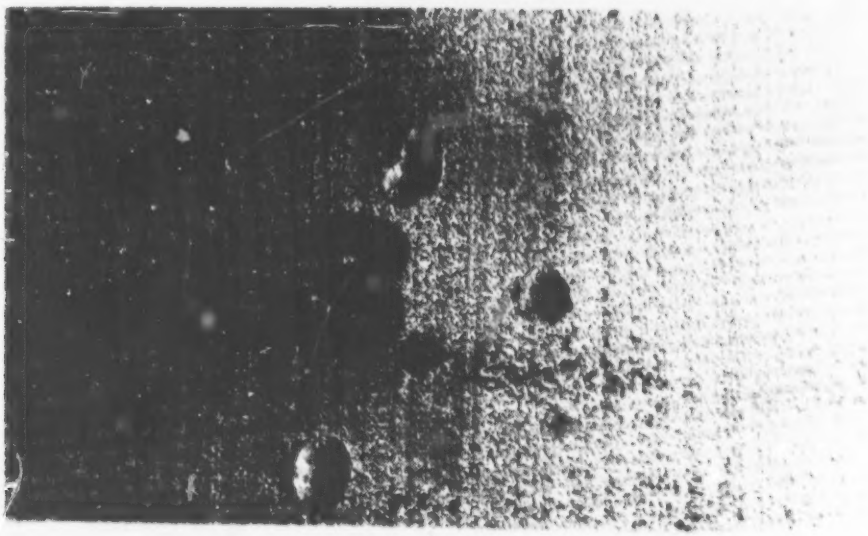
Baysilone



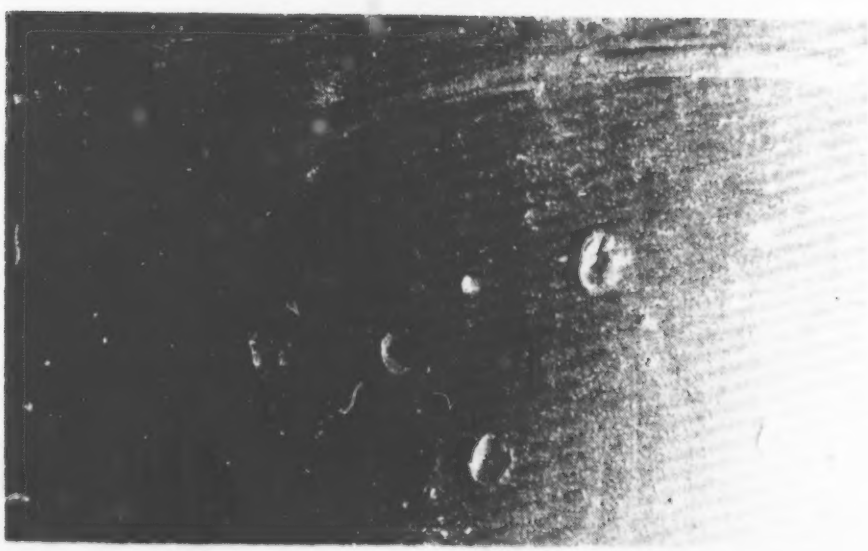
Defro S-III

FIGURE 3.17

IMPACT TEST



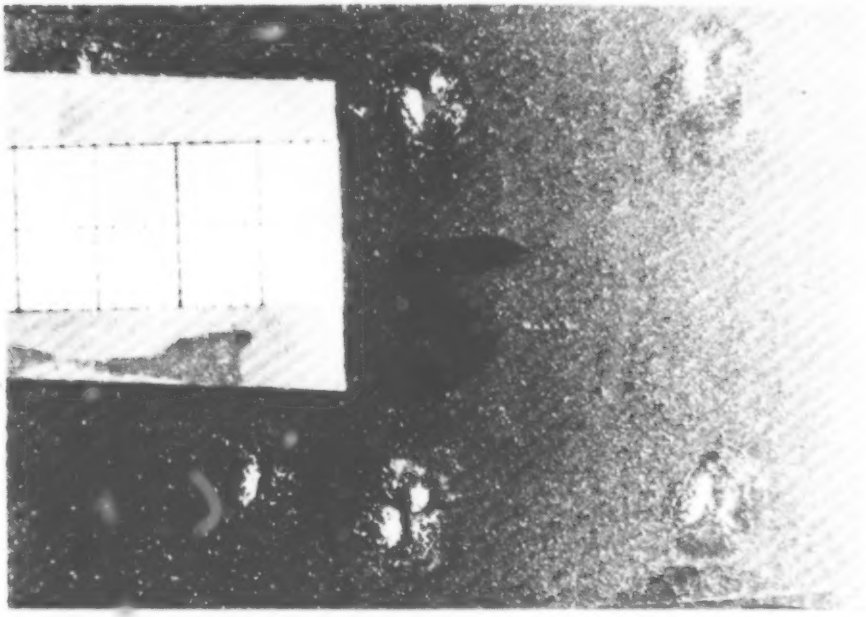
Hempel S-2104



Hempel S-2103

FIGURE 3.18

IMPACT TEST



Interslick

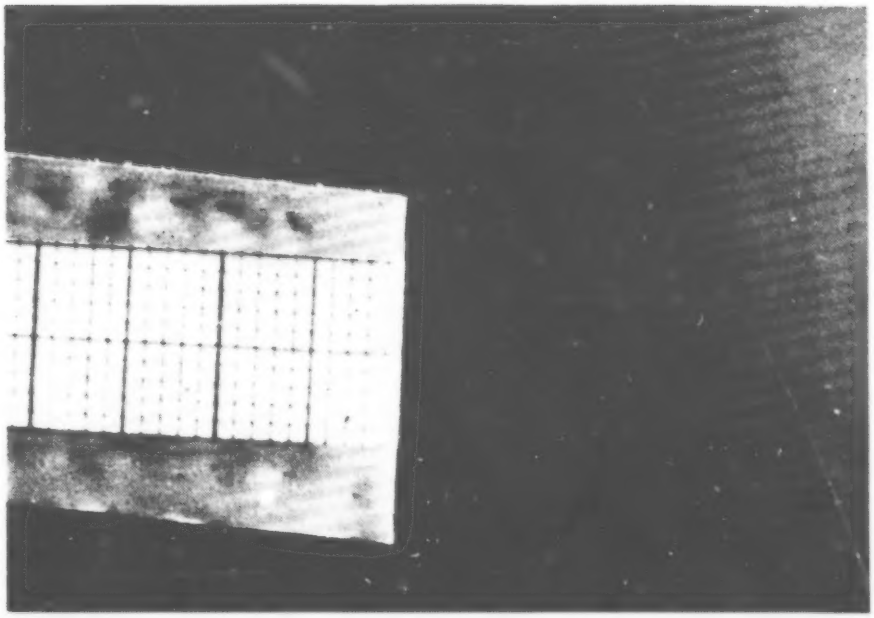


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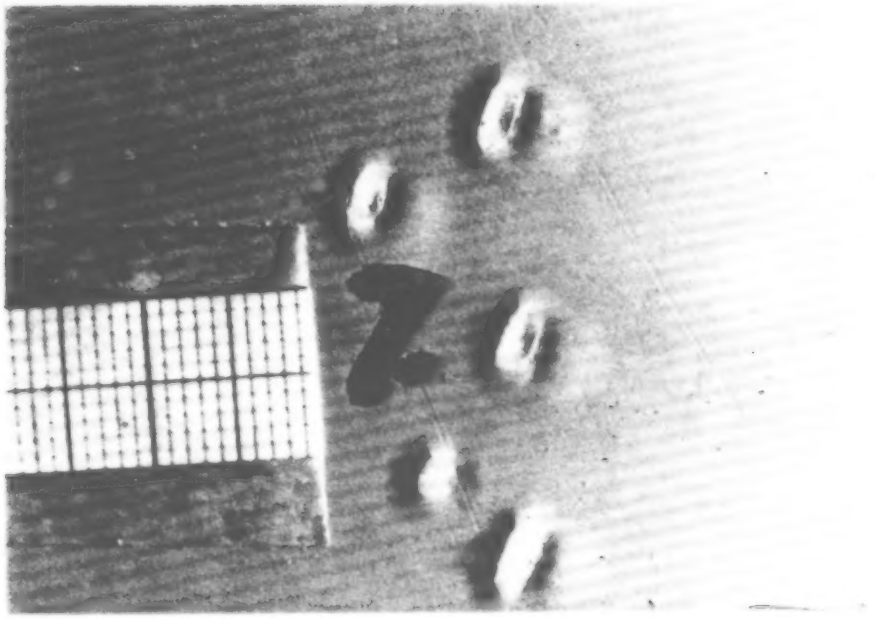
FIGURE 3.19

IMPACT TEST



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APPENDIX 3

SUMMARY OF ICING INCIDENTS

Summary of Icing Incidents Reported: February - March 1988

1. DATE: 26/02/88
   VESSEL: CAPE ROGER
   COMMENCED: 1230 Duration: 2.5 hours
   SHIP'S POSITION: 49° 57'W (long.) 46° 58'N (lat.)
   SHIPS HEADING: 0°, altered to 320° (NNW); Speed: 12.5 knots (average)

   TEMPERATURES: Air = -0.5°C; Sea = -0.63°C
   WIND: 15 knots at 020° NE
   SEA STATE: nil; moderate swell
   PRECIPITATION: light

   ORIGIN OF ICING: atmospheric
   SEVERITY OF ICING: light

2. DATE: 04/03/88
   VESSEL: SANDERLING
   COMMENCED: 2200 Duration: 8 hours
   SHIP'S POSITION: Pier 36, Halifax Harbour
   SHIPS HEADING:

   TEMPERATURES: Air = -1°C; Sea = N/A
   WIND: 11 to 16 knots NW
   SEA STATE:
   PRECIPITATION: light

   ORIGIN OF ICING: atmospheric
   SEVERITY OF ICING: very light

3. DATE: 14/03/88

VESSEL: CAPE ROGER

COMMENCED: 0400 Duration: 4 hours (see precipitation notes)

SHIP'S POSITION: 52° 57'W (long.) 43° 31'N (lat.)

SHIPS HEADING: 080° ENE; Speed: 10.5 knots

TEMPERATURES: Air = 0.0°C; Sea = +3°C

WIND: 10 to 15 knots at 290° NW

SEA STATE: nil, light swell

PRECIPITATION: moderate-heavy; snow commenced at 2330, 13/03/88, transition to freezing rain as noted, to rain at 0800, 14/03/88

ORIGIN OF ICING: atmospheric

SEVERITY OF ICING: light

4. DATE: 16/02/88

VESSEL: CAPE ROGER

COMMENCED: 0100 Duration: 2.5 hours

SHIP'S POSITION: 52° 30'W (long.) 47° 10'N (lat.)

SHIPS HEADING: 005° NNE (true); Speed: 5 knots

TEMPERATURES: Air = 0.0°C Sea = +1.0°C

WIND: 25 knots NE

SEA STATE: moderate

PRECIPITATION: light to moderate

ORIGIN OF ICING: icing

SEVERITY OF ICING: light, hit heavy fog bank before observations, some degradation occurred

5. DATE: 22/03/88
VESSEL:
COMMENCED: N/A Duration: overnight
SHIP'S POSITION: 56° 35'W (long.) 47° 15'N (lat.)
SHIPS HEADING: 236° WSW Speed: 10.2 knots

TEMPERATURES: Air = -6°; Sea = +0.54°C
WIND: 35 knots at 260° WSW
SEA STATE: moderate
PRECIPITATION: moderate; snow/sleet

ORIGIN OF ICING: atmospheric and sea spray; noting water temperature, it is likely that the freezing spray was only a minor component of the icing
SEVERITY OF ICING: moderate

6. DATE: 12/01/89
VESSEL: CAPE ROGER
COMMENCED: 0900 Duration: 1.5 hours
SHIP'S POSITION: 48°24'W, 46°10'N
SHIPS HEADING: 310°, Speed 3 knots

TEMPERATURES: Air: -7°, Sea: 0.2°C
WIND: 40 to 50 knots, NW
SEA STATE: 15 to 20 feet
PRECIPITATION: light snow

ORIGIN OF ICING: sea spray
SEVERITY OF ICING: light

7. DATE: 14/01/89
VESSEL: CAPE ROGER
COMMENCED: 1000 Duration: 4 hours
SHIP'S POSITION: 47°55'W, 46°21'N
SHIPS HEADING: 270° Speed 6 knots

TEMPERATURES: Air: -5°C, Sea: 0.5°C
WIND: 25 to 30 knots, 030°
SEA STATE: 3 to 6 feet
PRECIPITATION: occasional snow

ORIGIN OF ICING: sea spray
SEVERITY OF ICING: very light

8. DATE: 21/09/89
VESSEL: CAPE ROGER
COMMENCED: 1200 Duration: 2 hours
SHIP'S POSITION: 52°28'W, 47°15'N
SHIPS HEADING: 180° speed 5 knots

TEMPERATURES: Air: -1.5°C
WIND: 30 knots changing from SE to SW
SEA STATE: 10 to 15 feet
PRECIPITATION: occasional snow

ORIGIN OF ICING: sea spray + atmospheric
SEVERITY OF ICING: light

9. DATE: 22/01/89
VESSEL: CAPE ROGER
COMMENCED: 0800 Duration: 3 hours
SHIP'S POSITION: 52°28'W, 47°20'N
SHIPS HEADING: 360° speed 4 knots

TEMPERATURES: Air: -4.5°C Sea: 0°C
WIND: 60 to 70 knots NWN
SEA STATE: about 10 to 15 feet
PRECIPITATION: none

ORIGIN OF ICING: sea spray
SEVERITY OF ICING: light

10. DATE: 27/01/89
VESSEL: CAPE ROGER
COMMENCED: 1400 Duration: 2.5 hours
SHIP'S POSITION: 52°50'W, 50°45'N
SHIPS HEADING: 360° speed: 4 knots

TEMPERATURES: Air: -1°C dropping, sea: -1°C
WIND: 60 knots
SEA STATE: 20 to 25 feet
PRECIPITATION: occasional snow

ORIGIN OF ICING: sea spray
SEVERITY OF ICING: light

11. DATE: 02/02/89
VESSEL: CAPE ROGER
COMMENCED: 0300 Duration: 6 to 8 hours
SHIP'S POSITION: 52°21'W, 48°30'N to 52°52'W, 49°0'N
SHIPS HEADING: 360° Speed: 6.5 knots

TEMPERATURES: Air: -6.5°C
WIND: 30 knots
SEA STATE: moderate NW
PRECIPITATION: none

ORIGIN OF ICING: sea spray
SEVERITY OF ICING: light

12. DATE: 17/02/89
VESSEL: CAPE ROGER
COMMENCED: 1915 Duration: 10 hours
SHIP'S POSITION: 49°03'W, 45°14'N
SHIPS HEADING: 275° speed 3 to 4 knots

TEMPERATURES: Air: -7°C sea: 0°C
WIND: 43 to 50 knots, 270°
SEA STATE: about 20 feet
PRECIPITATION: occasional flurries, then heavy snow

ORIGIN OF ICING: sea spray
SEVERITY OF ICING: moderate

13. DATE: 28/02/89

VESSEL: CAPE ROGER

COMMENCED: 0900 Duration: 22 hours

SHIP'S POSITION: $48^{o}20'W$, $47^{o}30'N$

SHIPS HEADING: 270^{o} speed: 10 to 15 knots

TEMPERATURES: Air: $-1^{o}C$ to $-3^{o}C$ Sea: $1.2^{o}C$

WIND: 35 to 40 knots, $270^{o}C$

SEA STATE: 7 to 14 feet

PRECIPITATION: fog and snow

ORIGIN OF ICING: atmospheric and sea spray

SEVERITY OF ICING: light

APPENDIX 4

INSTRUCTIONS ON EXPERIMENT MONITORING AND REPORTING

ANTI-ICING AND DE-ICING EXPERIMENTS ON M.V. CAPE ROGER

Instruction on experiment monitoring and reporting

The experiments prepared for the 'CAPE ROGER' are designed to investigate the efficiency of two methods to reduce the rate of ice accretion, or to assist in the removal of ice from surfaces, or a combination of the two. One of these methods is the use of recently developed ice phobic paints which may reduce the amount of ice accumulation on treated surfaces by causing the water droplets to shed efficiently and by reducing the adhesion strength of the accreted ice. The second method is based on the electrical heating elements, like heat tracing tapes, attached to the structures affected by icing. The third method makes use of inflatable panels which during inflation break and remove ice adhered to their surfaces. The last method is simply a small pneumatic hammer used for ice removal from decks and other easy accessible areas of the ship.

The general arrangement of the control panels installed on the front of the superstructure for these experiments is shown on the attached sketch. The following information provides guidance on how to make observations, and how to report the performance of the test panels if icing occurs.

A. GENERAL ICING CONDITIONS

General information about the weather and sea conditions, as well as about ship movements, is necessary for further analysis of the experiments in terms of methodology and potential for commercial applications.

Therefore, you are requested to provide this information by filling in the 'FORM A - GENERAL' whenever icing conditions are met.

B. ICE PHOBIC PAINTS

Plates marked with number 4 (from A to G) on the sketch are coated with ice phobic paints, except one plate with reference paint similar to that used normally for painting ship superstructures. The reason for installation of separate flat panels for evaluating ice phobic paints rather than painting some designated areas on the superstructure surface itself is a requirement to offset the control panel from the underlying surface by a significant distance to avoid ice bridging. If the samples of ice phobic paints were applied directly on the bulkhead, then ice accumulating on the surface surrounding a test area might form a continuous sheet across this area even though ice might not be adhering to it.

If icing occurs, the ice accretion rate may be different on each of the test plates. You will be requested then to record your observations by filling in the 'FORM B - ICE PHOBIC PAINTS'.

C. HEAT TRACING

Electrical heat tracing methods have been found to be quite efficient for de-icing of helidecks on offshore oil rigs. Newly developed heat tracing tapes may also be useful for de-icing of ship structures, and this experiment is designed to investigate such application.

The plate marked on the sketch with number 3 is fitted with the RAYCHEM self limiting heat tracing tape. The tape is installed in such a way, that its port side section will supply heat at the rate of 800 W/m^2 while its starboard side at 100 W/m^2 approximately. The heater is connected to the control panel consisting of the on/off switch, circuit breaker and control lamp, and located in the wheelhouse. In addition, the electrical circuit is connected to the electrical power demand analyzer in order to provide reliable record of the power consumption for de-icing purposes.

When the ship is affected by icing, you are requested to turn on the power demand analyzer, then, to turn on the heater and record de-icing process on the test plate. It is very important that you are familiar with operation of the power demand analyzer and that the instrument is properly set up for the measurements with one minute increments.

The heater and the power demand analyzer should be switched off as soon as the test panel is free of ice and turned on again during the next icing incident. This is required by the need of accurate recording of power consumption exclusively for de-icing purposes and saving the recording paper tape. However, the heat tracing tape, if not turned off on time, will not be overheated because it has a property to increase its electrical resistance with temperature, which means that when ice is removed and the plate getting warmer, the flow of the electrical current and hence generation of heat is minimal.

D. INFLATABLE PANELS

Each of the inflatable panels fitted to the front of superstructure consists of inner rubber cells built into an outer rubberized mat, such that, when the cells are inflated with air, they expand and the mat surface heaves the strerches and breaks the adhesion of ice to the mat surface. The panels are connected to a compressed air system through reduction valves which are set for the working pressures not higher than 10 psi. Controls for them are situated on the bridge.

If icing conditions are experienced, the ice should be allowed to build up on the de-icers to a thickness of about 0.5 inches before inflation. Only one panel at the time should be used in order to enable accurate observations of their performance.

E. AIR GUNS

This experiment is proposed with the intention of finding a mechanical substitute to wooden mallets which are presently used on ships for manual de-icing. Some researchers reported that air hammers could brake up large quantities of ice while causing less damage to bulwark and decks than the standard methods, provided that the rounded tips were used.

The supplied air hammer should be used in areas and circumstances which may indicate some advantages in using the air hammer over the wooden mallets.

FORM A

G E N E R A L

1. Date and time of encountered icing:

   Commenced:_____ Stopped:_____

2. Ship position and movements:

   Longitude:_____ Latitude:_____
   Heading:_____ Speed:_____

3. Weather conditions (please specify units):

   Air temperature:_____ Sea temperature:_____
   Wind direction:_____ Wind speed:_____
   Sea state:_____ Precipitation:_____

4. Origin of icing:

   [ ] - Atmospheric [ ] - Sea spray [ ] - Both

5. Severity of icing:

   [ ] - Light [ ] - Moderate [ ] - Heavy

6. Please take a few general photographs showing how the ship is affected by icing.

7. Please fill in the whole set of reporting forms for each of the icing incidents.

FORM B

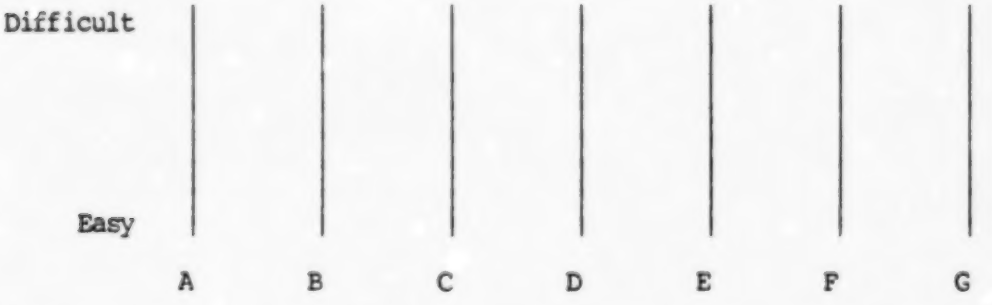
ICE PHOBIC PAINTS

1. Please make observations either from the wheelhouse wings or from the deck, if conditions allow. Make sure that your own safety is not jeopardized under any circumstances.

2. Please take a few photographs of the test plates and cylinders after occurrence of icing.

3. If there is a visible difference in the amount of ice accreted on the test plates, try to assess visually the relative amount of ice on each of the plates. Record your observation on the following lines:

4. If the access to the test plates is possible, try to move accreted ice from each of the plates by striking it gently. Mark on the following lines the relative difficulty in removing ice from the plates:



5. By measuring thickness of the removed pieces of ice, try to determine the average thickness of ice on each of the plates and fill in the following spaces, specify units (mm or inches):

A _____ B _____ C _____ D _____ E _____ F _____ G _____

FORM C

HEAT TRACING

1. Please make observations either from the wheelhouse wings or from the deck, if conditions allow. Make sure that your own safety is not jeopardized under and circumstances.

2. Please take a few photographs of the test plates fitted with electrical heat tracing elements before switching the heaters on and in course of de-icing in order to show a pattern of ice melting or shedding.

3. Note and record below times when the heaters have been turned on and when de-icing has been completed. If only a part of the test plate has been cleared of ice, please indicate percentage.

	Stbd plate (No. 1)	Center plate (No. 3)	Port plate (No. 5)
Time turned on:	.....	.....	.....
Time turned off:	.....	.....	.....
% of ice removed:	.....	.....	.....

4. Obtain a printout from the power demand analyzer, showing the rate of power consumed by the heaters, and attach it to this report. Make sure that the instrument is ready to carry out next set of measurements.

5. Give below your own comments, if you have any, on the performance and efficiency of the heat tracing panels and control equipment.

FORM D

INFLATABLE PANELS

1. Please make observations either from the wheelhouse wings or from the deck, if conditions allow. Make sure that your own safety is not jeopardized under any circumstances.

2. Please take a few photographs of the inflatable panels after occurrence of icing.

3. Try to estimate when the ice thickness on the panels is about 0.5 inches, then inflate one of the panels, take a few pictures, make necessary observations and then repeat this procedure with the other panel. Record your observations below:

	PORT PANEL	STARBOARD PANEL
Estimated ice thickness specify - mm or inches		
Inflation pressure (specify units)		
Percentage of ice removed		
Number of inflations		
Other comments		

4. Give all of your comments on the performance and efficiency of the inflatable de-icing panels below:

FORM E

AIR GUNS

1. Please make sure that while conducting experiments and making observations your safety is not jeopardized under any circumstances.

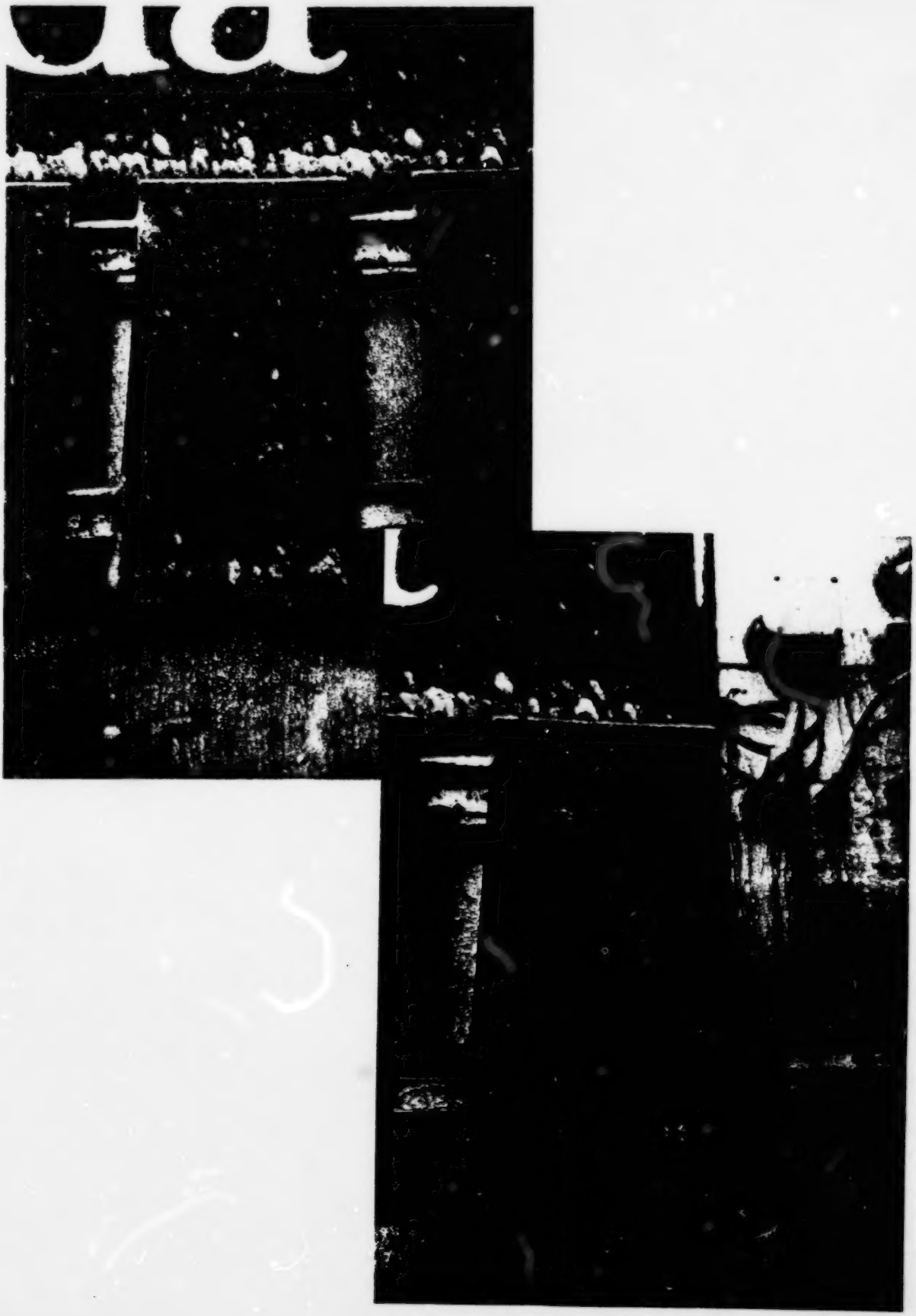
2. Please take photographs of the ice before, during and after removal by means of the air hammer.

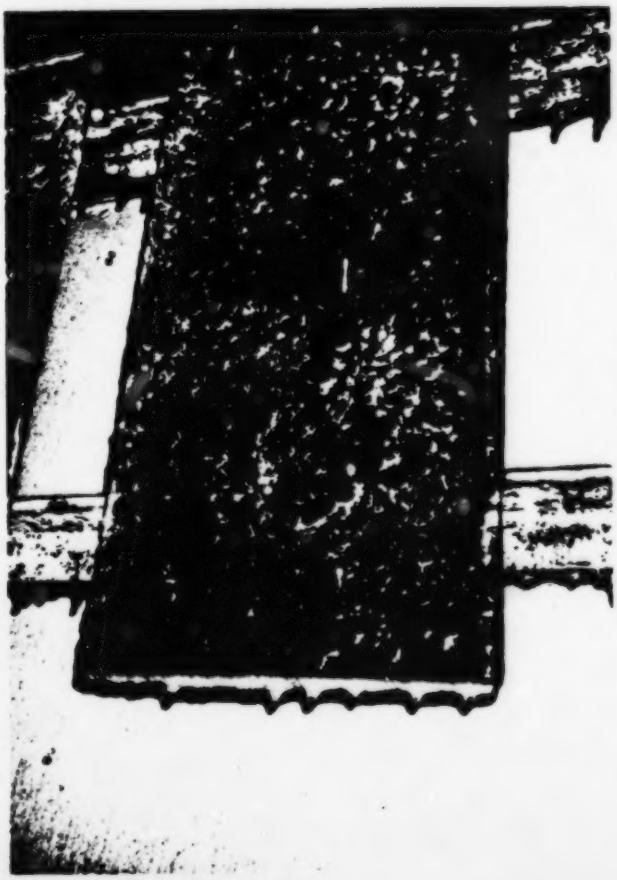
3. Describe the location of the iced up area and other relevant circumstances justifying the use of the air hammer. Give your comments on the performance of the air hammer.

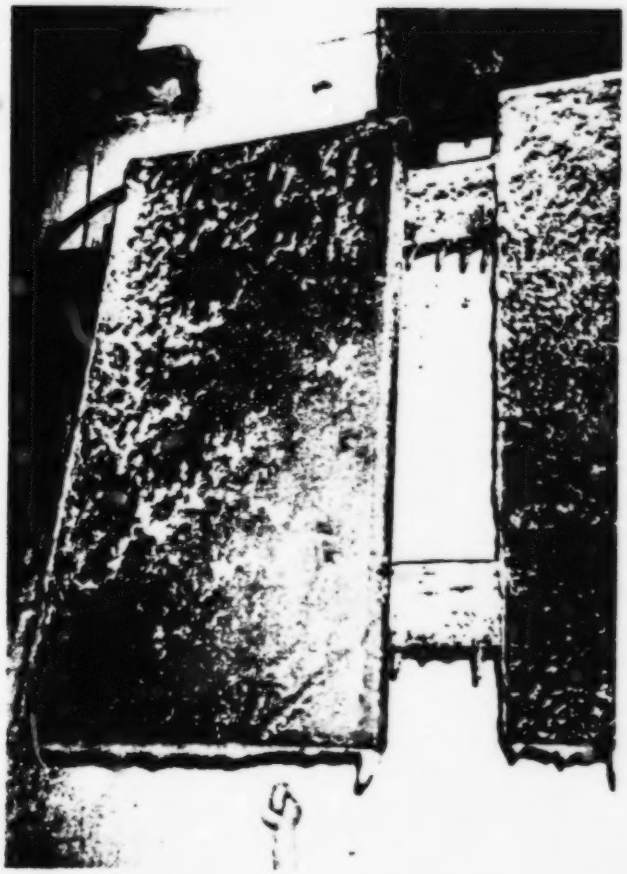
APPENDIX 5

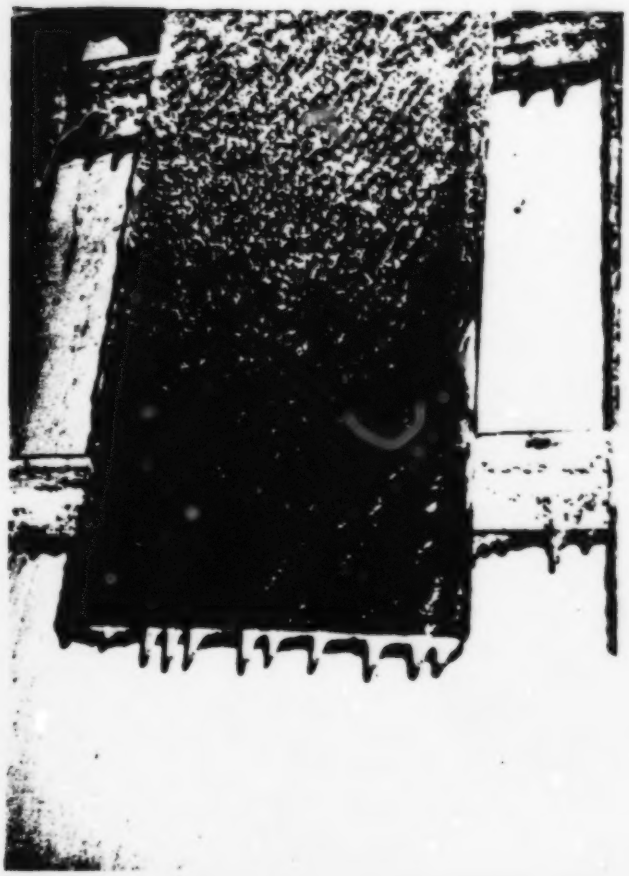
PHOTOGRAPHS OF ICING ON ICE PHOBIC PAINT PANELS AND CYLINDERS

Canada









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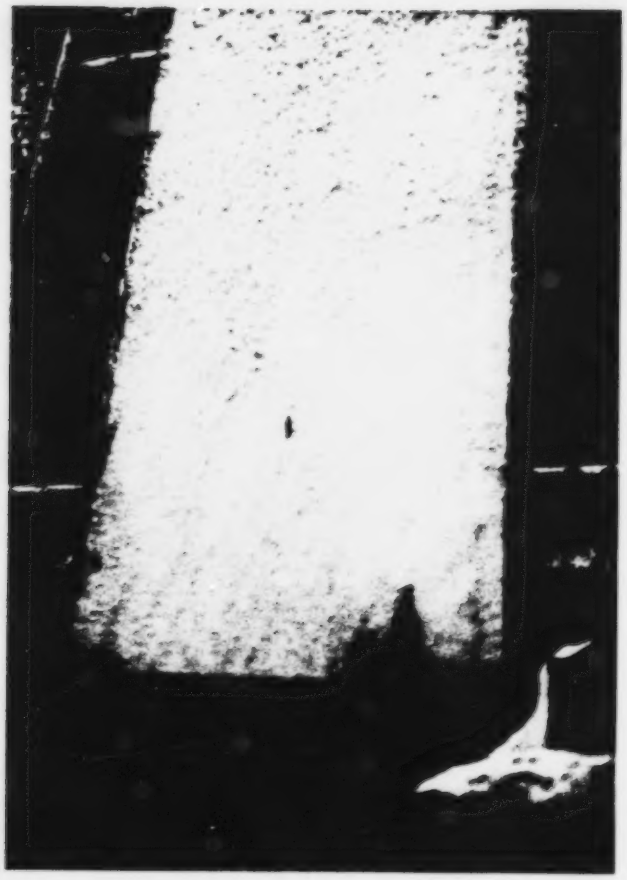

APPENDIX 6

PHOTOGRAPHS OF ICING ON HEATED PANELS

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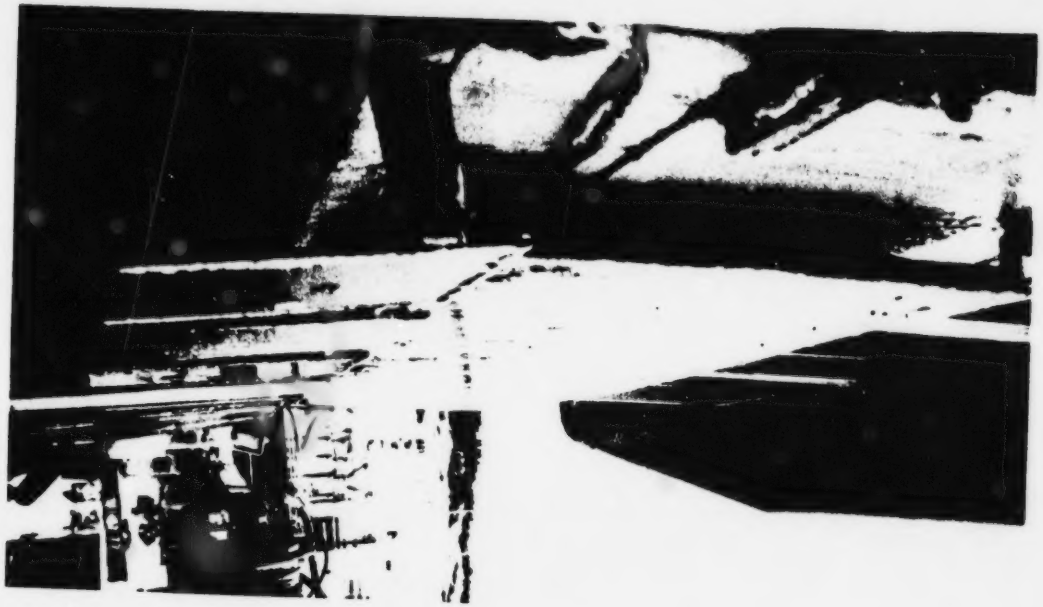

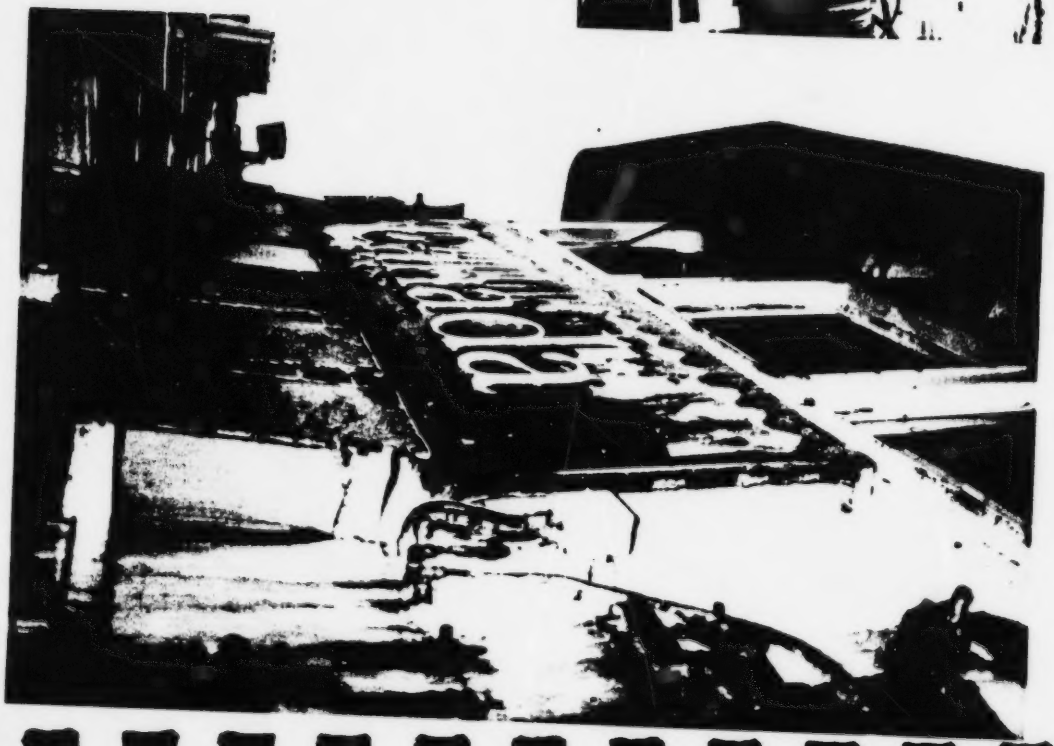

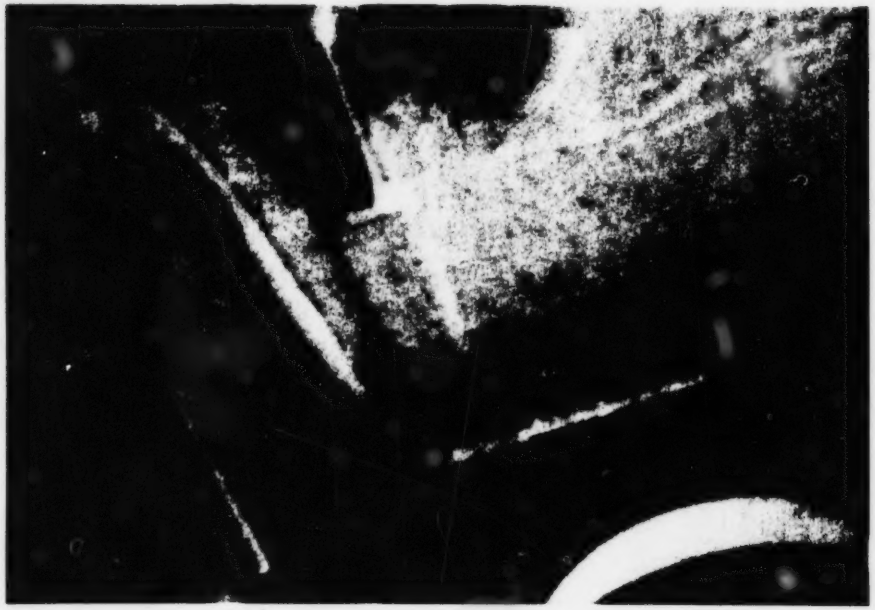

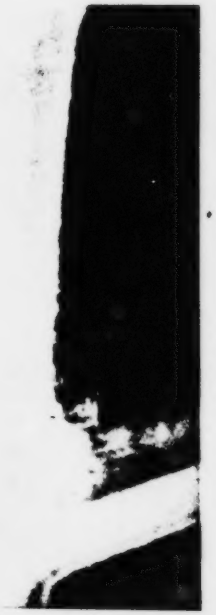

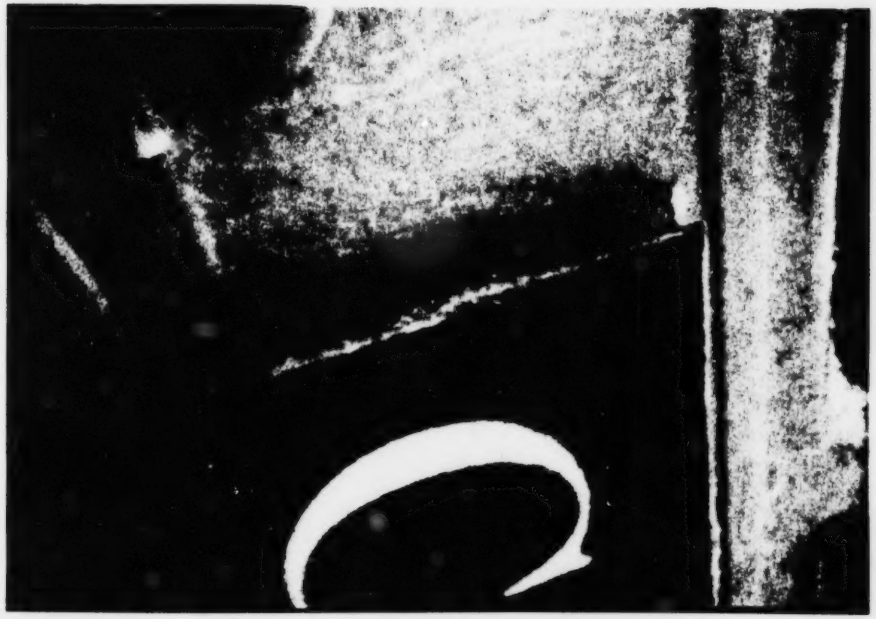

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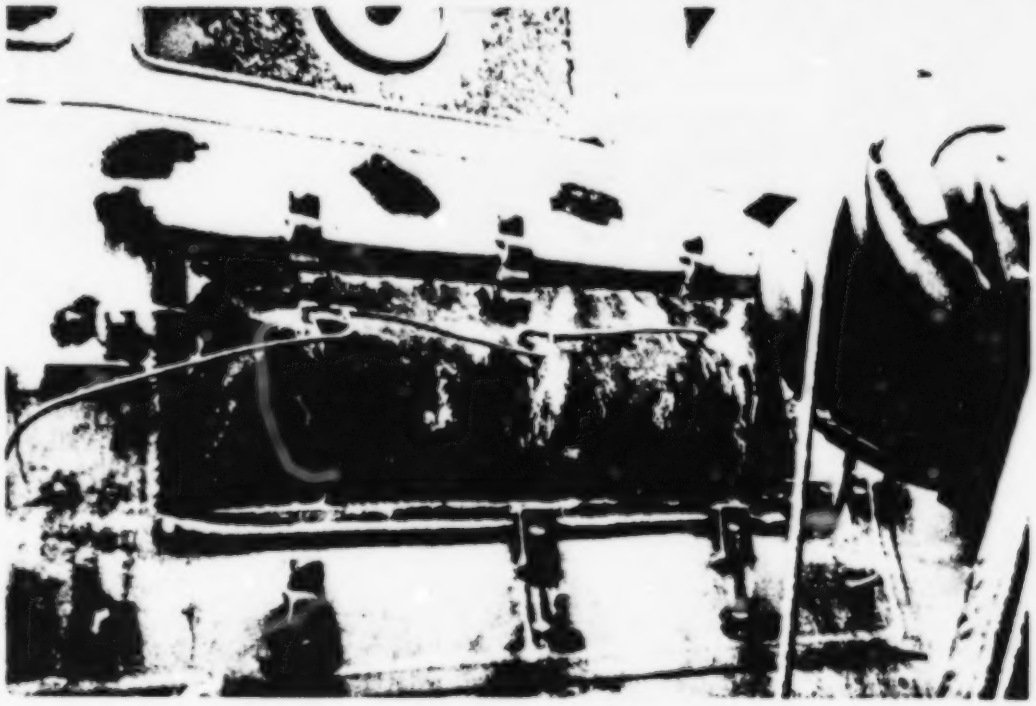
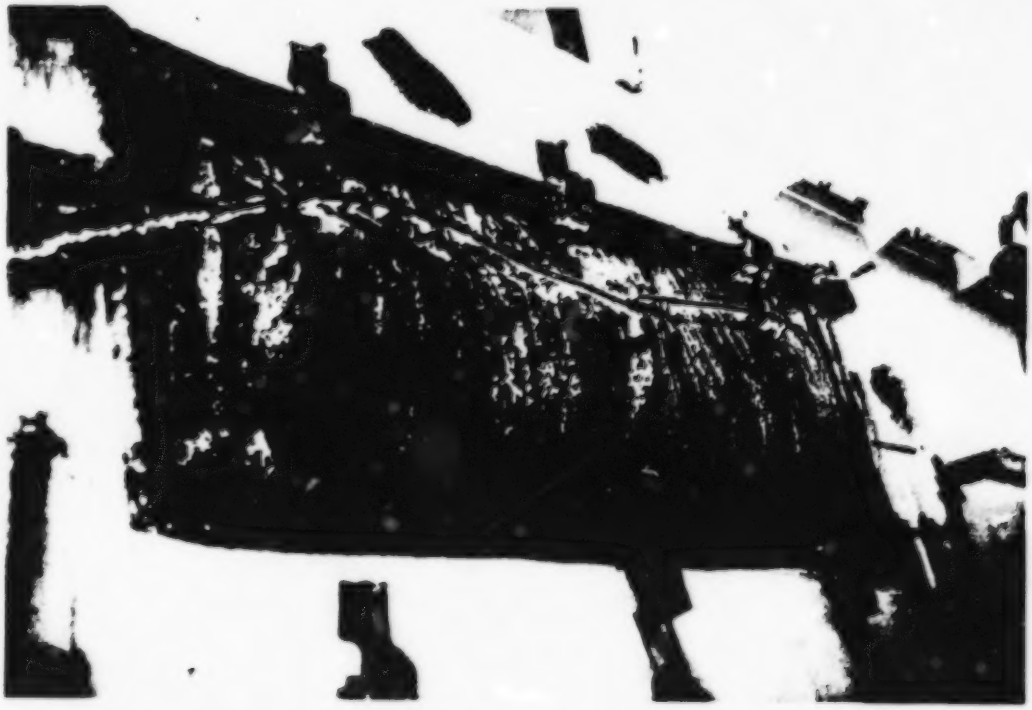
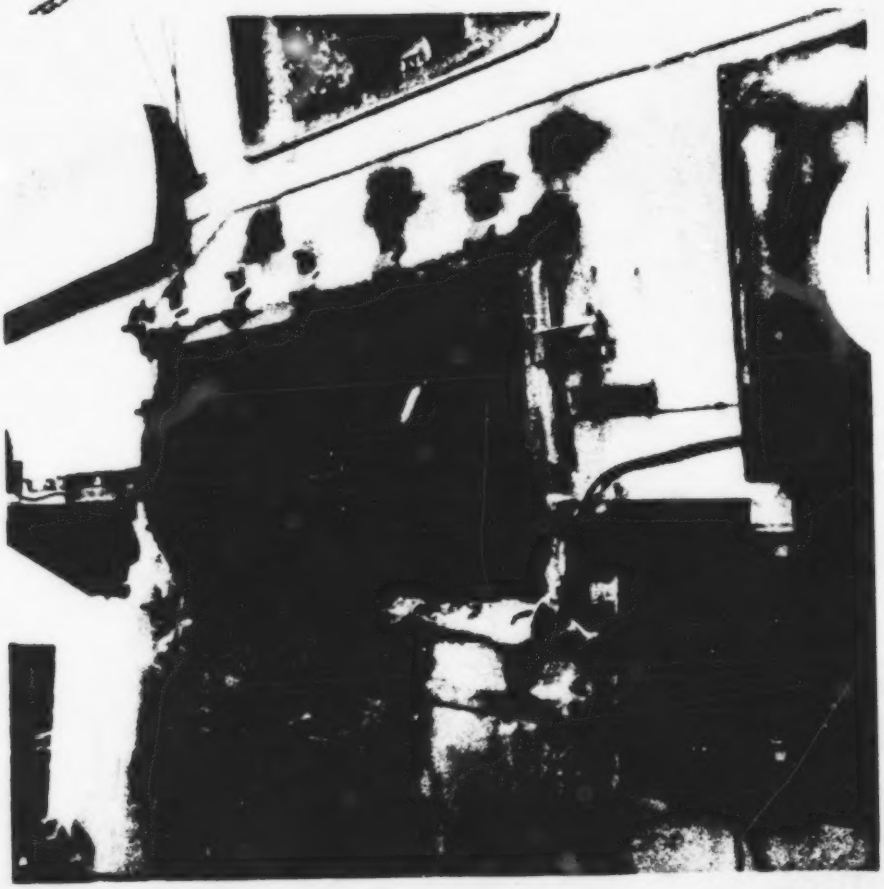
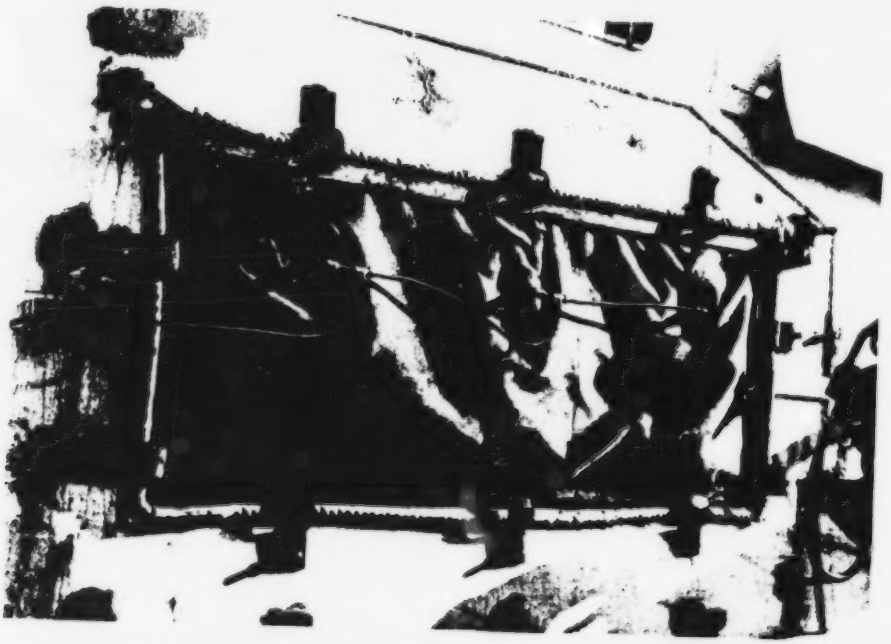
APPENDIX 7

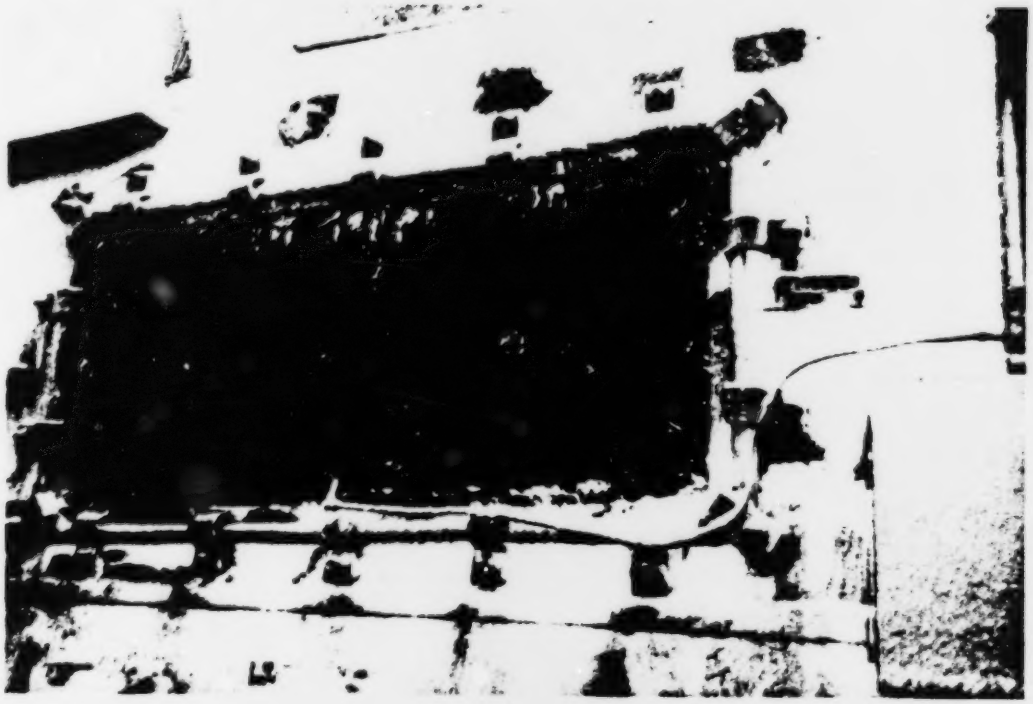
PHOTOGRAPHS OF ICING IN INFLATABLE PANELS

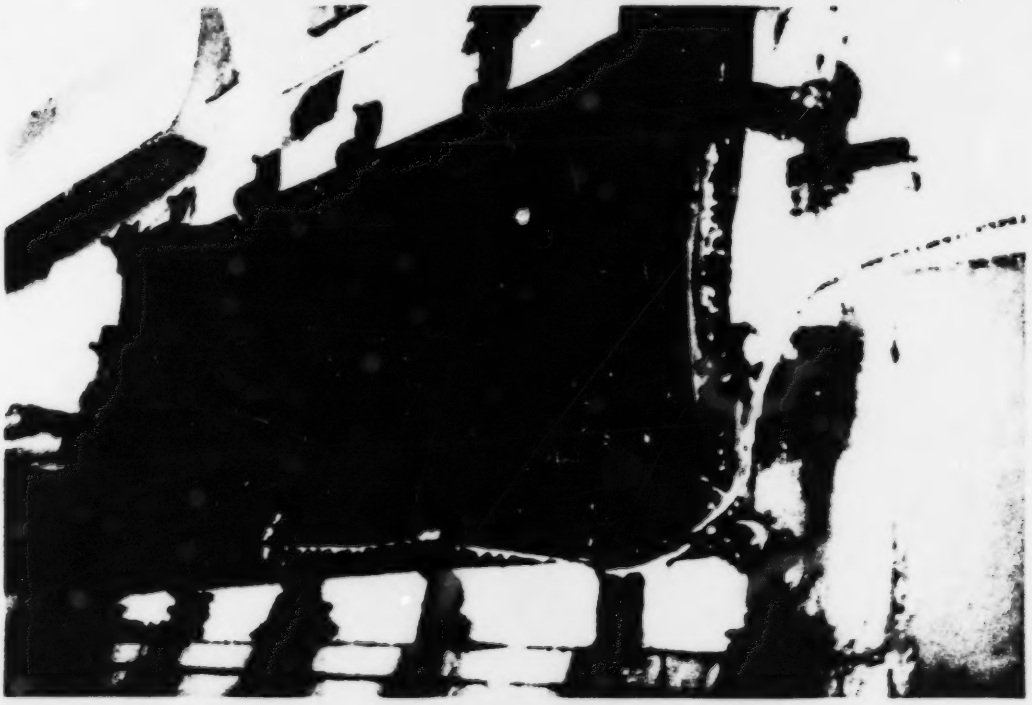






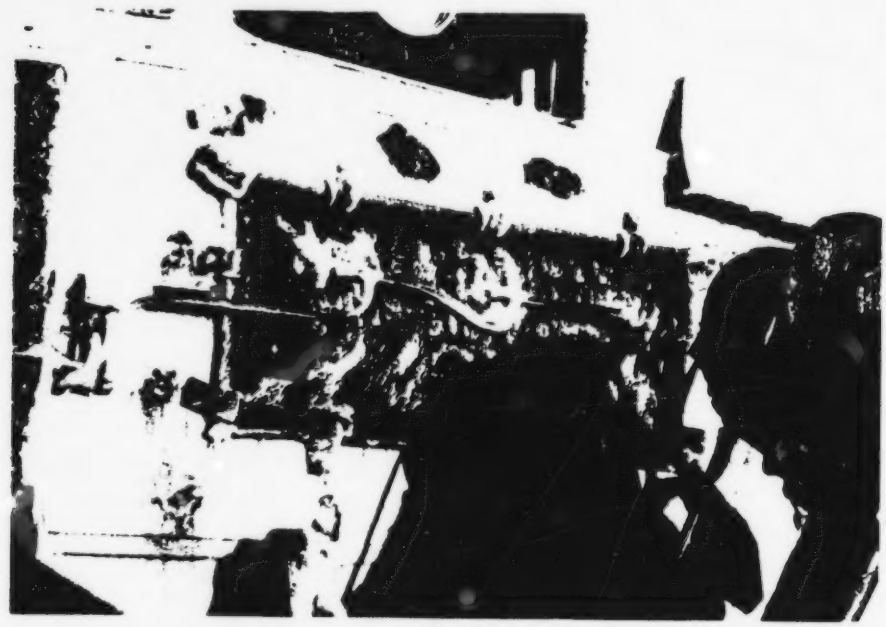


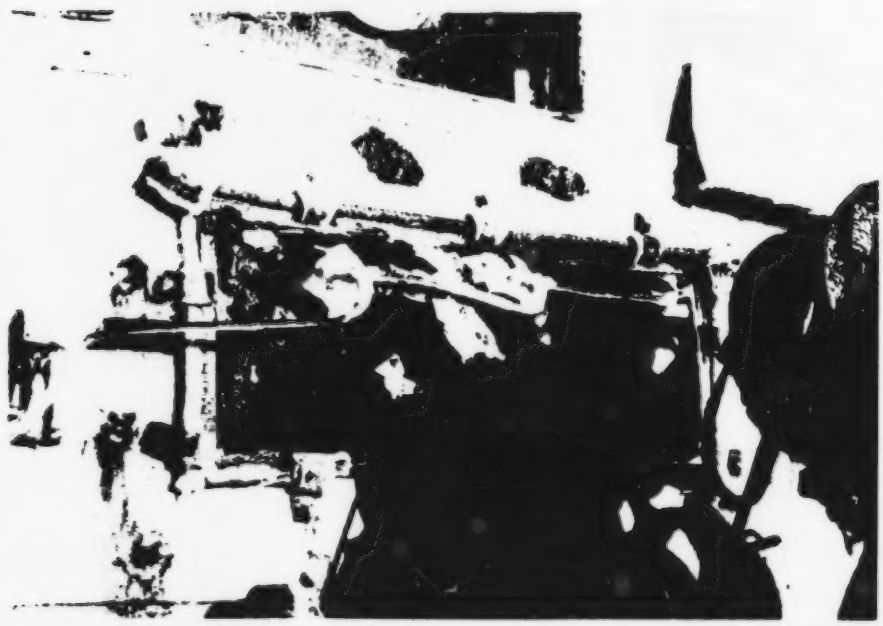




January 28, 1989

Port side inflatable panel before and after inflation. Ice thickness 7-8 mm, inflation time 30 seconds, air pressure about 70 kPa.





Canada

APPENDIX 8

ABSTRACTS OF SELECTED LITERATURE

TITLE: Icing of Ships

AUTHOR: H.R. Bardarson

SOURCE: (See Bibliography)

ABSTRACT:

The paper discusses the reason for ice accretion on ships with particular reference to fishing vessels. It reports on the icing predictions made by the Icelandic Meteorological office and how they compare with icing experienced by fishing vessels.

The effect of icing on ship stability is considered and methods whereby the danger of icing can be reduced are presented.

TITLE: The Ice Accretion Problem in Canadian Waters Related to Offshore Energy and Transportation.

AUTHOR: Brown R.D. & Roebber P.

SOURCE: Atmospheric Environment Service 1985 (unpublished Manuscript)

ABSTRACT:

The objectives of the study were to:

(1) Delineate the scope of the icing problem in Canadian waters identifying offshore industry needs for icing-related information

(2) Compile and analyse a database of vessel icing information from Canadian waters.

The report includes a general discussion on icing of offshore structures and aircraft, a discussion of the characteristics of icing in Canadian waters.

Problem areas in the modelling of ice accretion on ships and structures are identified and anti- and de-icing strategies discussed. The results of consultations with the offshore oil industry and regulatory bodies are also included.

TITLE: A Numerical Sea Spray Icing Model Including the Effect of a Moving Water Film

AUTHOR: I. Horjen & S. Vefsnmo

SOURCE: International Workshop on Offshore Winds and Icing, Halifax 1985

ABSTRACT:

A theoretical model is presented for calculating icing intensity, heat of anti-icing and the thickness and vertical velocity of any brine film covering the ice surface. Wind stress effects are neglected and the brine is hence moving only by the action of gravity. It is found that the transport of brine on the icing surface reduces the icing intensity significantly. The brine movement has no effect upon the heat of anti-icing, provided no icing is permitted at all in the wet icing region.

TITLE: Influence of Ice Accretion on Activity in the Northern Part of the Norwegian Continental Shelf

AUTHOR: T.S. Jorgensen

SOURCE: Offshore Technology Testing & Research Group, Trondheim
Report N° 5TF88 F82016 1982

ABSTRACT:

The report is an approach to the problems of icing on offshore activity based on a literature survey on icing at sea. The various meteorological and vessel- and structure-dependent factors of significance to the phenomenon of icing, and the hazards of icing on vessels, platforms and helicopters are discussed.

The work carried out to improve the safety by introducing minimum ice loads, and the probabilities of icing dependent on meteorological conditions and various waters are described.

Actions against icing as icing warnings, design and handling of vessels and platforms are discussed, and various mechanical, thermal and chemical de-icing and anti-icing methods are described.

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TITLE: Some Aspects of Ice Formation with Special Reference to the Marine Environment

AUTHOR: Lock, G.S.H.

SOURCE: Transactions of the North East Coast Institution of Engineers & Shipbuilders 1972

ABSTRACT:

The study attempts to give an understanding of the thermal and dynamic characteristics of atmospheric ice in general and accretion on ships in particular. A detailed description of wind tunnel experiments is reported and comments are made on various techniques for controlling shipboard ice.

TITLE: Investigation & Research on Anti-icing & De-icing Devices for Marine Application

AUTHOR: S. Loset

SOURCE: International Workshop on Offshore Winds and Icing 1985

ABSTRACT:

Drilling rigs and ships, supply vessels and standby boats for all year operation in the hostile waters offshore Northern Norway need to be winterized in order to obtain high regularity and safety. The Norwegian Marine Technology Research Institute A/S (MARINTEK) has therefore tested cost-effective anti-icing and de-icing devices for use on these offshore units in order to prevent or reduce ice accretion which might occur offshore Northern Norway.

This paper describes some laboratory experiments performed in MARINTEK's climate chamber where offshore arctic climate is reconstructed, and reveal some results from the field experiments carried out offshore Northern Norway.

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TITLE: Atmospheric Icing on Sea Structures

AUTHOR: L. Mankkonen

SOURCE: U.S. Army Cold Regions Research & Engineering Laboratory 1984

ABSTRACT:

The problems atmospheric icing causes for ships and offshore structures are revised. Estimation of the probability and severity of atmospheric icing based on climatological factors is discussed and theoretical methods for calculating the intensity of atmospheric icing at sea are suggested. Methods of measuring icing rate and icing prevention are also presented.

TITLE: Assessment of Ice Accretion on Offshore Structures

AUTHOR: L. David Minsk

SOURCE: CRREL 1984

ABSTRACT:

The conditions of ice accretion on vertical and horizontal surfaces are given all of which will be present in Alaskan offshore sites, data from ships cannot be applied to offshore structures and can only indicate probability but not severity conditions conductive to ship icing are given. A scarcity of appropriate meteorological data is noted, and data requirements are presented together with a method of measuring spray icing. Tests of icephobic coatings are discussed and recommendations are put forward on icing data collection and means of measuring ice accretion. Recommendations are also made on future work which should be undertaken.

TITLE: Marine Climatological Atlas - Canadian East Coast

AUTHOR: L.D. Mortsch: T. Agnew: A. Saulesleja & V.R. Swail

SOURCE: Atmospheric Environmental Service (1985) (Unpublished Manuscript)

ABSTRACT:

The Canadian east coast offshore is a frontier area where severe and often limiting environmental conditions occur. It is necessary to incorporate an understanding of meteorological and oceanographic phenomea when designing hydrocarbon exploration and production facilities and support systems, designing aircraft, and planning search and rescue operations and contingencies for the marine environment.

This marine climatological atlas was compiled as an aid for structural designers, operational planners, marine scientists, and regulatory agencies. Wind, waves, air and sea surface temperature, precipitation, humidity, windchill, ice accretion sea level pressure, flying weather, and visibility (shipping weather) are summarized. Some statistical analyses are directly applicable to design. For example, extreme value analysis of wind speed and wave height are necessary to define design loading criteria. Statistics such as percent frequency of VFR flying weather or wind roses are important for defining operating windows and contingencies.

This atlas represents a synthesis of information from ships-of-opportunity, land station, and ocean weather station Bravo data sets, the hindcast geostrophic winds (GWC), and the spectral ocean wave model (SOWM) waves. These data sets have been selected as the most appropriate for the statistical representations for design. The uses and limitations of, and the quality control checks performed on the data sets are described in Sections 2 and 3, respectively.

TITLE: Studies of Ice Accumulation on Ships Part II

AUTHOR: N. Ono

SOURCE: National Research Council (Translation)

ABSTRACT:

Ships sailing the northern seas in winter encounter the phenomenon of icing: sea water in the form of spray (or otherwise) freezes onto the ship's structures. The accretion of ice raises the vessels' center of gravity and causes a marked loss of stability, which may finally lead to capsizing. The accumulation of ice on ships is therefore to be classed as one cause of marine disasters. On a small fishing vessel, operations may be suspended when icing begins and the whole crew may be employed in removing the ice. But when the rate of icing goes up into the tons per hour and ice removal does not keep pace with ice accretion, or when the crew has no knowledge of icing, then finally the disaster of capsizing occurs. If steps are to be taken in good time to prevent such disaster, it is essential to have information on the ice accretion process. We need to observe the conditions for icing to occur, and the weights of ice accreted; we need studies of how icing affects stability, so that the safety characteristics of the ships may be improved; we need to examine methods for the prevention of icing and we need to enhance the efficiency of ice removal.

The Maritime Safety Agency undertook to carry out, each winter from 1960 on, a series of tests with ships at sea, using the Agency's patrol ships and others. The results for each year have been reported pari passu [1-4], and the findings of the tests up to and including 1962 have been recapitulated in a previous paper [5].

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TITLE: Icing of Ships

AUTHOR: V.V. Panov (1976)

SOURCE: Translation - Polar Geography II (3) P166-86 July-Sept. 1978

ABSTRACT:

The increasing use of Arctic shipping lanes by the Soviet Union has focused attention on the problem of icing of ships, mainly from sea spray formed during strong wave motion or as a combination of precipitation and spray. Icing poses a threat in ice-free seas rather than in drift ice, and the highest frequency has been observed in the Barents Sea, at the western end of the Arctic shipping route, and in the Bering Sea and Sea of Okhotsk, at the eastern end, the most common period being December through March. In the central portion of the Arctic (Kara, Laptev, East Siberian and Chukchi seas), icing poses a problem during the summer shipping season (June through November). Icing conditions are analyzed on the basis of Soviet and non-Soviet observations.

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TITLE: The Probability & Intensity of the Icing Up of Ocean Going Vessels

AUTHOR: A.N. Shekhtman

SOURCE: Ministry of Defence 1968 (Translation 1971)

ABSTRACT:

This paper reviews the conditions which lead to ice accretion on ships statistics are presented for the winter of 1965-66 in the Barents Sea, Norwegian, Greenland and Berring Seas and Seas of Japan and Okhotok which show that fast, slow and constant icing occurs over a wide range of temperatures of $+6^{\circ}$ to $-1.7^{\circ}C$. Although sea spray is the primary cause of ice accretion, atmospheric icing can also lead to dangerous conditions on board ship.

TITLE: Hydrometeorological Conditions in the Icing of Vessels at Sea

AUTHOR: A.N. Shekntman

SOURCE: Naval Research & Development and Administration, Ministry of Defence 1971

ABSTRACT:

A survey is given of literature about the icing-up of vessels and the results of a summary of several hundred factors concerning this dangerous occurrence and the accompanying hydrometeorological conditions. The circumstances of icing-up are defined more accurately, and recommendations for the further study of hydrometeorological factors which influence the icing-up of vessels are given.

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TITLE: Icing of Fishing Vessels in Canadian Waters

AUTHOR: J.R. Stallabrass

SOURCE: National Research Council 1975

ABSTRACT:

The icing-up of their vessels is a perennial hazard faced by crews fishing in cold northern waters. This is particularly true for the Canadian east coast fisherman each winter, since conditions conductive to icing may exist from the moment he leaves port and at any time while steaming to or from the fishing grounds and while actually fishing; in fact his whole trip lies within a zone of potential icing.

The conditions necessary for ship icing are generally accepted (but with some disagreement as to precise limits) to be the simultaneous occurrence of air temperature of $-2^{o}C$ or lower, water temperature of $+6^{o}C$ to $-2^{o}C$, and wind speed greater than 20 knots. In addition the vessel's speed and heading relative to the wind and sea must be such as to produce significant amounts of spray over the vessel. If atmospheric precipitation, fog or sea smoke prevails in addition to sea spray, the combined effect is to produce more severe icing than would result from one source alone.

To effectively combat the icing problem it is first necessary to have a thorough understanding of its causes and the physical processes involved as well as an awareness of the true extent of the hazard. This paper presents a review of the present knowledge of these processes as well as offering a tentative assessment of the extent of the problem as related to the Canadian fishing fleets.

TITLE: Trawler Icing - A Compilation of Work Done at N.R.C.

AUTHOR: J.R. Stallabrass

SOURCE: National Research Council 1980

ABSTRACT:

This report collates and reviews the results of an eleven-year project on the icing of fishing trawlers.

Initially the factors causing the icing of ships at sea are presented and some aspects of the physics of the icing process are discussed.

Some simple icing tests on cylinders of various diameters are described. These were made in an icing wind tunnel and demonstrated the effects of air temperature and cylinder size on the resulting ice formations. Later, a number of possible methods for reducing the icing hazard were tested in the wind tunnel and at an outdoor test rig. Of the methods tested the most effective was an inflatable rubber de-icing blanket.

Throughout the project, icing report forms were distributed to vessels operating out of Canadian east coast ports. The data obtained by this means has helped to establish the types of weather systems responsible for icing conditions, the geographical extent of the occurrence of icing, and statistics on the severity of icing encounters in the study area.

Appendices present simplified formulae for the droplet collection efficiency of cylinders and rectangular bodies, the derivation of an analytical expression for the rate of ice build-up on fishing trawlers, and a bibliography of ship icing.

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TITLE: Research on Prevention of Ship Icing

AUTHOR: T. Tabata

SOURCE: Hokkaido University Institute of Low Temperature Science (1964)

ABSTRACT:

It is well known that on ships sailing the northern seas in winter, the phenomenon of icing may occur: sea spray or sea-surface fog ("Arctic smoke") freezes onto the ship's structure. During the first world war icing proved very troublesome for naval vessels on the North Atlantic; during the second world war icing was responsible, it is said, for the sinking of a British battleship. In 1955 it was reported in the news that two 1200-ton trawlers were sunk off Greenland as a result of icing. In the Soviet Union too the number of ships lost by icing has risen to a quite considerable total, and in USSR shipbuilding practice the loss of stability due to icing is now being taken into account, on the basis of predicting probable amounts of ice accretion.

As for Japan, with the area of fishing operations extended as in recent years, there is no way of recording how many fishing vessels may have been lost by ice accretion in the regions off the Soviet Far Eastern Maritime Province, the Kamchatkan Peninsula, and the Kurile Islands.

In Great Britain, the United States and elsewhere, research on the facts of ice accretion has been in progress. In Japan too icing research was carried out by the Maritime Safety Agency in the period 1960-1964, and we have obtained a clear picture of the influence of icing on ship stability. We are, furthermore, working out ice norms for patrol vessels: That is, criteria for the amounts of ice accretion that should be allowed for in ship design.

In spite of these research efforts, however, the relationships of ice growth to atmospheric and sea conditions are still inadequately resolved. Moreover, no successful methods for preventing ice accretion or getting rid of accreted ice have as yet been established.

TITLE: Hydrometeorological Conditions Causing Ice Accretion on Ships

AUTHOR: G.V. Vasil'yeva

SOURCE: Rybnoye Khoxiaistva (Fisheries) 1966

ABSTRACT:

The article presents information on the hydrometeorological conditions which favour ships and ice accretion and briefly discuss the weather conditions which promote icing.

TITLE: Icing & De-icing of Marine Radar Aerials

AUTHOR: H.L.H. Ward

SOURCE: Ministry of Defence Navy Department U.K. 1970

ABSTRACT:

This report describes tests which were carried out in a climate test chamber to assess the effects of ice accretion on continuously rotating commercial radar aerials the results indicated a very high loss in radar performance caused by only 1/4" to 1/2" of ice, and it is considered important that some means be devised for removing ice or preventing its formation. Tests are currently being conducted on the effectiveness of a pnumatic system using an inflatable rubber "overshoe" fitted over the front of the aerial.

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